HINTS ON WATER SUPPLY

BY L. L. MACASSEY C.E.

HINTS

ON

THE WATER SUPPLY

OF

SMALL TOWNS AND VILLAGES

BY

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PREFACE.

WITH the exception of the chapter on Hydraulics, the following pages are intended for general readers. Much of the matter has already appeared, but in so technical a form as to be entirely useless to all but Engineers. An attempt has been made by the author to state, in a concise and simple manner, the leading principles of Water Supply. Much of the opposition to Sanitary Reform is due to selfishness and ignorance, and it is hoped that these pages may assist in removing such impediments by showing that an ample supply of good water is essential, and well worth paying for.

Prior to the passing of the Public Health (Ireland) Act, 1874, many difficulties existed in the way of water supply to small towns and villages. A few of the towns were under the control of Commissioners, whose exertions seldom went beyond the cleansing of the streets and such sewers as existed. A dread of high rates prevented any attempt being made to introduce water for domestic use, and nothing was done, save, perhaps, the sinking of a few wells. In the villages matters were quite as bad, if not worse. Here the Grand Jury had the control of the streets and drains, and the inhabitants had to draw their supply of water from the neighbouring streams and springs. Such was the state of things existing when the Public Health Act came into operation; and though there has not yet been sufficient time to judge by results, it is evident that in many important particulars the provisions of the Act will prove highly beneficial, more especially in the country districts.

Under the provisions of the Act, the Board of Guardians of each Poor Law Union is constituted the Sanitary authority of the district, and of all towns therein, with the exception of those having a population of more than 6,000, or those having Commissioners acting under local Acts. The Act further provides that the Sanitary authority may supply places within its district

with water, or may contract with persons or companies to furnish the same; compulsory powers are also granted for the acquisition of lands and water rights.

With a view to the proper carrying out of the provisions of the Act, certain officers are appointed by the Sanitary authority. These are the Sanitary officers (the Dispensary Doctors), the Executive Sanitary officers (the Clerk of the Union or his Deputy), and, in certain cases, a Superintendent Medical Officer of Health. It is the duty of those officers to take cognizance of all Sanitary matters embraced in the Act, and, where requisite, to bring them under the notice of the Sanitary authority.

Of all the matters thus brought forward, the most important is Water Supply. This may refer to the quantity or quality of existing supplies, or to the question of supply to districts entirely deficient in such. In the discussion of such questions, the Sanitary authority has the assistance of the District Inspectors of the Local Government Board, gentlemen thoroughly versed in Sanitary science. When improvements have been decided on by the Sanitary authority, the Local Government Board, by their Engineer, examines into the details of the case, and decides whether the plans proposed are likely to prove efficient or otherwise, and advises the Sanitary authority accordingly. With such machinery for obtaining information of a reliable character, it is evident that improvements will not be entered on without a good prospect of success, and ratepayers may therefore rest assured that their money will not be spent rashly, nor without due inquiry.

The question of Water Supply is one which will present many points of difficulty to Guardians and Sanitary officers. To many the subject is entirely new, and though in the more important cases professional assistance is called in, yet a general knowledge of the subject will be found most useful by those charged with the investigation and carrying out of schemes of improvement. To give this information, and thus supply a strongly felt want, the present work is brought forward, and it is hoped it may prove serviceable in this respect.

Belfast, 1877.

HINTS ON WATER SUPPLY.

CHAP. I.—INTRODUCTION.

The following "Hints" are issued with the view of throwing some light on a most important subject. Sanitary reform is now the question of the day, and its leading item is Water Supply. Progress in this department has hitherto been confined to the large towns, where means were available for the construction of useful though necessarily costly works. The inhabitants of the smaller class of towns and villages have been left to their own individual efforts, whilst the lack of funds and rating powers has put a veto on improvements, and crippled the efforts of those anxious for the public good. This difficulty has now been removed, and Ireland stands on the same footing as the sister kingdom. The Public Health Act has put it within the power of the various local authorities and Boards of Guardians to provide a supply of water, either supplemental or otherwise, to the towns and villages within their districts. In fact, the matter is not left optional with the local authorities, but is made compulsory; and neglect or delay in carrying out the provisions of the statute, is wisely anticipated and provided for. Object of the Treatise.

In deciding on the best means of supplying a town with water, professional advice and guidance is essential. Hence it is not to be understood that these "Hints" are put forward in lieu of such advice. In many cases, when an engineer is called in to advise on matters of water supply, he is compelled to ground his opinion, and frequently design his scheme, on the information and data put before him by local authorities or their officials. This is frequently the

case. Where a town or district to be supplied is limited in extent, the various facts bearing on its supply with water are generally collected after months, and sometimes years, of discussion and observation by parties interested. In too many instances, unfortunately, for the engineer and his employers, he is called in after everything is cut and ready, and his duty merely consists in putting into shape the ideas and crotchets of leading members of provisional committees.

The object of the following "Hints" is, therefore, to guide local authorities as to the scope and direction of their inquiries, and to indicate the particular points upon which accurate information is to be obtained. Attention to the following particulars will supply clear and reliable data to lay before the engineer when he is called in.

Various works have been published by eminent authorities on water supply, but these are only available to the professional reader. Many of these have been consulted and borrowed from, though, of course, much valuable matter is omitted, owing to the difficulty of conveying it in a manner suitable for a popular reader. An attempt is made in the following remarks to simplify the subject, hence, technical detail is avoided as far as possible.

Schemes of Water Supply.

Like other matters of a practical character, the question of water supply is usually referred by local boards to a committee of its members. The duty of this committee is to collect all the information that may prove useful, or have a bearing on the question. Members of such a committee are frequently at a loss as to what points should engage their attention, and it is hoped that the following suggestions may serve as a correct guide.

A thoroughly perfect scheme of water supply can seldom, if ever, be devised within reasonable limits of outlay. Perfection of design and detail frequently mean large expenditure. Hence a compromise between efficiency and economy has generally to be adopted, and the scheme which possesses fewest defects, and entails only a moderate outlay, is usually carried out.

Importance of a good Water Supply.

The importance of an abundant supply of good water to the inhabitants of a town or district cannot be overrated.

The evils arising from the want of such a supply have long been known to scientific men, but, like many other branches of useful information, this knowledge has been treated with indifference and contempt by the public generally. In Ireland, this is especially true. The popular notion has been that, since our forefathers drank dirty water, we may do the same with impunity—a doctrine which has this point in its favour, that neither the present nor former generations indulged to excess in the use of water of any kind. With most people cleanliness is ranked next to godliness; but certainly the interval between them must be exceedingly wide, if the popular rendering of the first-named virtue be a correct one. To some minds a fair proportion of dirt gives the idea of comfort and homeliness, and the advocates of improvement are met with indifference, if not absolutely opposed. Many diseases are directly due to bad water, and many more are aggravated by its use. Statistics prove beyond a doubt that epidemics are both induced and extended in their range and virulence by the use of tainted water. One instance by way of proof will speak for itself. During the visitation of cholera in London, in the year 1853, it so happened that a large district was supplied with water by two competing Companies. The population of the district was about 500,000. Of these about 100,000 were supplied by wells, and the remaining 400,000 drank the water of the Companies. The rival mains frequently passed through the same streets. The several classes of the population were exactly similar in their circumstances and surroundings save in the matter of their water supply. One Company drew its water from a point far up the river Thames. This water was comparatively pure. The other Company took theirs from a point lower down the river. This was afterwards found to be strongly tainted with sewage matter. On the cessation of the epidemic, inquiries were made, and the following are the results, viz :—That in those houses supplied with the pure water, the cholera death-rate was 37 per 10,000 during the visitation ; and in those houses supplied with the tainted water and dependent on wells, the cholera death-rate was 130 in 10,000 of the population—the total deaths

from cholera being 4,000. Every care was taken to avoid error in these figures, and they were arrived at after a most careful inquiry, and a house to house visitation. This same district had suffered from cholera in 1848, when the death-rate was found to have averaged 120 in 10,000 of the population, and to have been pretty equal in all the houses in the district; but the remarkable fact was discovered that in 1848 the pure water had not been introduced, and the whole population were dependent for their daily supply on the tainted water of the other Company and on that from wells. No conclusion can be drawn from the foregoing facts but one, and that a most saddening one, that in the years mentioned, the lives of some thousands of human beings were sacrificed by the use of tainted water, sold to them by a commercial company.

The foregoing instance may be regarded as extreme and overdrawn, but it is vouched for on the best authority. By it the effects of tainted water were proved on a large scale. Many more cases might be quoted where the results were less marked, owing to the districts being more limited in extent. The greater number of our small towns and villages have their water polluted, and the causes of this pollution are often winked at. This is the case especially in manufacturing districts, where the working population are frequently dependent for their drinking water on the streams used partly or entirely by the manufacturers. Fortunately, public opinion is undergoing a change, and large employers of labour, landlords, and local boards, are beginning to see that common justice demands that they should provide a fair supply of pure water to the public under their care.

Effects on Sewerage.

Another strong argument for an abundant water supply may be drawn from its effects on the sewerage of a town or district. The efficiency of the latter is almost entirely dependent on the former. Without plenty of water to flush a sewer, it must in time become utterly foul, and a source of danger, and often death. Medical statistics tell us what our sewers have done and are doing. Many a good life has been cut short by breathing the subtle poison from the foul drains of a town or village; and but one remedy is available, and

that is plenty of water to flush away the source of the evil. Covering the refuse matter of a town in sewers does not avoid danger: the evil is still ready to do its work when escape for gas is afforded. Out of sight out of mind, does not hold good in this case.

Some reformers advocate the dry closet system, by which much of the matter now passing into sewers would be disposed of in another way; but so long as water closets are in use, they must be fairly supplied with water, otherwise they become highly dangerous. In many of the smaller towns no water is available for cleansing purposes, save during the rainy season. Each autumn, as it comes round, finds the sewers choked with solid matter of all kinds, thoroughly putrid, and evolving dangerous gases. When a good supply of water is afforded the inhabitants, this evil does not arise, because the greater part of the water will find its way, after use, into the sewers, and by its scouring agency prevent those accumulations which are so much to be dreaded. This view of the case is strongly borne out by the fact that when an epidemic makes its appearance in many of our small country towns, it is just as severe as in larger ones, taking into account the difference of population. The large towns labour under the drawback of having less pure air, and of being more closely inhabited; but, as a rule, their systems of water supply and drainage are complete and efficient. The small towns, on the other hand, are well situated as regards air, and are more openly built but are defective in their water supply and drainage, and to this fact is due the unfavourable comparison they make with large towns. Enough has now been said to show the paramount importance of a good supply of water, and it is now proposed to refer more in detail to the several points demanding attention.

Chap. II.—Requirements of Towns.

Consumption of Water.

GENERALLY the first question to be discussed and decided by those parties charged with the supply of water to a town, is the total daily quantity required. This is usually stated as so many gallons per head of the population to be supplied. The last is easily arrived at, and the quantity per head must be settled after due inquiry. The consumption of water in a town may be classed under the following heads:—For Domestic use; Cleansing of sewers; Public drinking fountains; Cattle supply; Special objects; and lastly, Manufacturing and Trade purposes. These are placed in their order of importance. In the case of large towns, the last item in this list takes a more leading place. In small towns, where manufactures are carried on to any extent, the parties concerned generally look after their own interests; and, unfortunately, these interests do not always tend to the public good. Hence the matter of supply for manufacturing purposes is not deserving of much attention at the hands of local authorities. The first point to be considered is the proper quantity to be supplied for purely domestic purposes. A few figures will prove a help in this direction. The average number of members in each family or household is abont five. Each person will require about 2 gallons per day, either as food or drink, or for cooking purposes; for personal cleanliness, 1½ gallons are necessary; and for washing clothes, washing floors, and other household purposes, the required amount will be 2½ gallons per head. These figures bring the quantity required for domestic use up to 6 gallons per head. This is the very lowest figure that can be set against family consumption. Where baths are in many of the houses, an additional allowance must be made for them; where many horses or cows are kept, as in many country towns, a further addition must be made. For sewer cleans-

ing, such as house drains, water closets, and washing yards, about 2 gallons will be the minimum allowance. For public drinking fountains, about 2 gallons will do. In the case of special supplies no exact amount can be set down; each case must be determined on its own merits. Waste of water must also be taken into account: this will occur in spite of every precaution, and the very lowest figure that can be set against it is 2 gallons per head. We have thus a minimum of absolute requirement of 8 gallons per head per day, and nothing less should be aimed at in the smallest town.

Variation of Demand.

As will be readily seen, the supply required will range from the amount first stated to a very wide maximum. The causes of such variation are very numerous. In small towns and villages, the inhabitants will draw their water direct from public fountains, and the labour of carrying it to their houses will check even its proper use. In better class towns the residents will have the water piped in, and there will be a considerable number of baths and water closets, all drawing their supply from the public mains.

The following scale of supply per head, for various populations, will be found useful :—

Population.			Gallons per head	per day.
500	...	...	8	,,
1,000	...	...	10	,,
2,000	...	...	12	,,
5,000	...	...	15	,,
10,000	...	...	17	,,
15,000	...	..	19	,,
20,000	...	...	20	,,

The above populations are assumed to be those of towns where manufactures are not largely carried on. In the case of the latter, additional supply must be provided, according to circumstances. In general practice, for towns of medium extent, the rule is to secure a supply of not less than 20 gallons per head per day, but like most general rules, it is open to many exceptions. The following towns are supplied as below :—

Edinburgh,	...	...	30	Gallons per head per day.
Glasgow,	...	...	38	do.
Manchester,	...	...	22	do.

Liverpool,	... ...	27	Gallons per head per day.
Dublin,	... ...	20	do.
Belfast,	... ...	23	do.
Armagh,	... ...	15	do.
Newry,	... ...	30	do.
Holywood, Proposed,	...	30	do.

Possibility of Increase.

In deciding on a proposed supply, the parties charged therewith should take into consideration the possible increase of the population in the future. The only guide on this point is the past increase, and the probability of its continuance in the same ratio. As far as possible, the nature of the supply, and the works proposed to be executed, should be such that extension can be properly carried out in the future without requiring any interference with the system. Regard should also be had to the prospects of a special supply of water being required for any purpose, and due provision be made; by so doing, a saving can often be effected on the annual rates for domestic purposes.

CHAP. III.—SOURCES OF SUPPLY.

Sources of Supply.

THE sources from which water may be derived for the supply of a town are various, though they are themselves directly attributable to rain-fall. These sources may be classed as follows :—Springs, Rivers, and the water running off a given surface or district, or, as it is generally termed, a drainage area. As will readily be seen, these sources of supply are frequently closely related ; for the surface water of a district gradually forms rivulets, and eventually streams and rivers. Outflows of springs, in a similar manner, collect into lower levels, and find their way to the nearest stream or river, whose volume they swell. Before throwing out any suggestions, as to the selection of a source of supply, a few words describing the nature of these sources will be necessary.

Rain-fall.

Springs are the result of two well-known laws in nature, viz., that water, the flow of which is uncontrolled, will pass from a higher to a lower level; but if confined or obstructed, it will seek escape from such confinement by the first available channel. The rain which reaches the ground from the clouds is distributed into three portions. One portion passes into the ground and percolates the materials of the latter. A second portion flows off more or less directly as surface water, and, following the lowest levels, reaches the nearest stream. The third portion is lost, as far as a source of supply, being absorbed by vegetation, or evaporated by the heat of the ground and atmosphere. In accordance with the first law mentioned, the water passes from the surface to lower levels. The ratio which these portions bear to each other, or to the total quantity of rain-fall, varies within very wide limits. The quantity of spring forming water depends on the materials passed over or through. The third portion, or what may be called lost water, depends for its amount on the nature of the vegetation, the soil, prevalent winds, and temperature ;

whilst the second, or surface drainage water, depends on the first and third, and is in fact the difference between these and the total rain-fall. The usual way in which these proportions are defined is as per centages of the total rain-fall. The first step in deciding on the suitability of a supply is to determine with the greatest exactness possible the total rain-fall and the per centage of the three portions abovementioned. Rain-fall is generally measured in inches for a year, a month, or a day. That is, vertical inches. For example, the term, " one inch of rain in 24 hours," means that if the water had not flowed away, or been absorbed or evaporated, it would have measured one inch deep over the entire surface upon which rain had fallen. The amount of rain-fall per annum in any district is dependent upon many general and local circumstances. Influences, such as the temperature of the district, its lie as regards prevailing winds, its mountainous character, or otherwise, have much to do with the rain-fall. The theory of rain-fall, and its variations in different localities, is yet imperfectly developed. The laws governing these variations are pretty well defined in character, though not in individual effect or value, so that it is still impossible to calculate the probable rain-fall of any given district under examination with anything like certainty. The only method is to measure or gauge the fall of rain. This is done by means of a rain-gauge. These instruments are of various forms, but for a description of them I must refer to works of a more complete and technical character than the present. It may be mentioned that a simple form of gauge can be made as follows :—Take a tin platter, with a turned rim ; the lid of a water-can will do. Make a hole about the centre of the tin, and into this hole insert a small lead pipe, say $\frac{1}{4}$ inch bore, making the joint tight with solder. Set the tin with the pipe unfastened into the neck of a glass bottle, the latter being put underground. The rain will then fall on the tin and flow into the bottle, from which it can be poured out for measurement. The latter will be done as follows :—Take a glass tube, closed at the lower end with a cork and sealing wax, and whose area bears any given proportion to that of the tin. A given

Rain-Gauge.

depth of rain on the whole surface of the tin will, when poured into the tube, stand at some determinate height, and, having once ascertained the relative proportions of tin and tube, any other quantity may be determined. Taking, for example, a tin with a diameter of six inches, and a measuring tube of one inch diameter, the proportion of their areas will be as 6^2 to 1 (since the areas of circles vary as the square of their diameters), or as 36 to 1. Supposing a rain-fall of say 1 inch on the tin, and pouring it into the tube it would stand in the latter at a height of 36 inches. Next suppose this total height divided into ten equal parts, each of these would represent one-tenth of an inch of rain on the gauge. Again, were these tenths sub-divided in the same way, each of the smaller divisions would represent 1-100th of an inch of rain on the gauge. Or, in other words, the readings on the tube would be 36 inches high=1 inch rain; 3·6 inches high=0·10 inches rain; and 0·36 inches high=0·01 inches rain. If, then, the tube be made 3·6 inches long, and divided into tenths by lines scratched on it, any quantity of rain up to 0·10 inches can be measured, and ten fulls of the tube will represent one inch rain. If the district to be experimented upon be small and uniform, one gauge will suffice; but should it be large, and divided up into valleys by ridges of high ground, several should be used. For purposes of water supply the total fall only is required; it is safer, however, to measure and record the rain-fall each day, and note the weather and wind. Accident or mischief frequently robs a rain-gauge of its contents, a mishap not very serious even should it occur when the gaugings are taken every day. The nearest official or private register of rain-fall should also be obtained, and the figures compared. These registers are now numerous through the country. A comparison of the gaugings with those of the nearest record for the past and current year, will give an idea whether the latter is above or below the average in respect to its rain-fall.

Having now determined the total rain-fall in any district, the next step is to divide it into the three portions already mentioned. This is generally very difficult, and frequently impossible. By gauging the streams which are

formed by the surface water of a district, the latter can be arrived at. The difference of total rain and the surface water represents the quantity absorbed by the ground and vegetation, and that evaporated. A portion only of the water absorbed by the ground can be received by the surface springs and streams, and the proportion that this bears to the total depends on the nature of the ground by which it is absorbed, and through which it passes.

Springs.

Taking, then, the sources of supply in order, we begin with springs. These, as above mentioned, are either surface springs or underground, as in wells. The difference in these is merely one of level. The principles to which the action of springs is due has been touched upon. Water passes down through the pervious beds, until it is stopped by some impervious bed, such as clay or rock; it then collects, and its surface is raised, until escape is afforded by the porous beds. The point of escape generally forms a surface spring. The latter may be conveniently situated as a source of supply, and when such is the case, the first step is to gauge the flow of the spring in the driest season; and when the flow is sufficient and the water good, no source of supply is more desirable, both on grounds of efficiency and economy, as expensive works are avoided. It must, however, be borne in mind that the variations of rain-fall are reproduced in springs, though not to such an extent nor so rapidly as in the case of surface streams. Springs are sometimes very powerful, but, as a rule, several of them must be made available for a source of supply.

Wells.

In many cases surface springs are not to be found within convenient reach of a town or village, and recourse must be had to well sinking. This simply means making an opening through the porous strata or beds, until the line of saturation or top line of the water stored underground is reached, and the water will then flow to the opening, whence it can be made available by means of a pump or lifting apparatus. The action and working of underground springs is pretty well understood, but the theory is not yet sufficiently complete for practical application. Our knowledge will tell us on sinking a well why we have succeeded, but it

is far from being a safe guide in pointing out where to make a sinking with a fair prospect of success. General rules are laid down, but they are liable to many exceptions. The most careful calculations are frequently upset by some unexpected fault or fissure in the underlying strata. Sometimes several wells have been sunk successfully in a neighbourhood, and an attempt to get water close to one of these may turn out a failure, though to all appearances the local circumstances are identical. This shows the great uncertainty attending well-sinking. A few general remarks may, however, prove of service. In looking for an underground spring, the beds should be carefully examined and compared wherever they are exposed. Where a water-tight stratum underlies a porous bed, water may be looked for with a fair prospect of success. When a well reaches the water-tight bed it should not be carried further down, for there is a possibility of the water being lost in the porous beds below. An impervious bed of rock, overlaid with shivers, or rotten rock, as it is frequently termed, generally yields water. Sandstone rock, with beds of sand above, sometimes gives large quantites of water. The most convenient point for reaching the water-bearing strata should be selected, so as to avoid the expense of deep sinking.

Objections to a Well Supply.

Though the above remarks are made, it is not to be understood that a well supply is to be recommended in many cases. Sometimes there is no other resource available, but where possible, some other means of supply should be selected. Wells are too frequently the receptacles of drainage waters when they pass through porous beds. The water carried from the surface must pass into them, and convey with it its usual burden of decaying matter. Nearly all the surface soil about towns and villages is saturated with sewage and organic matter, and of these the well gets its full share. Another objection to well water is the fact that it is generally charged with solid matters in solution, and consequently hard; but this will be touched on hereafter. When, however, a well supply is unavoidable, the following precautions should be kept in view. The site of the well should be at a considerable distance from

the inhabited part of the district. The sinking should be made, if possible, on high ground, where the surface drainage will be from the well and not towards it. When the beds passed through are porous, the well should be lined with brick in cement, so as to be water-tight, and further, the light should be carefully excluded. These precautions, if observed, will remove some of the dangers arising from the use of well waters. Wells cannot be recommended for the larger classes of towns or even villages. They may do in small villages, where the inhabitants draw and carry home their daily required quantity of water. Where the latter has to be distributed, a well supply is not available without pumping machinery and its consequent annual charge. Many towns are partly supplied from wells, but, as a rule, instead of multiplying these, local authorities are looking to other and better means of supply.

Rivers. The next source from which a supply of water may be obtained, is a River. When the latter is considerable in volume, the quantity required for a small town may generally be obtained without difficulty, and without the construction of large storage works. The simplest way to test this point is to gauge the river during the dry season, and compare the results with the requirements of the district to be supplied. **Gauging.** Where the river is not too large, the best way to do this is to select some level part where the banks are pretty high, and straight, and throw across a plank deep enough to cause slack water for some distance up stream. The plank should have a check in it, cut sufficiently deep to pass the greatest run of water. The bottom and sides of the check should be chamfered off to a thin edge—the latter being to the up stream side. This allows the water to pass freely away. A stump or peg should then be put into the bed of the river above the plank, and its head level with the upper edge of the check. The whole should then be made tight with puddle, so as to send all the water over the check. By taking the depth of water on the peg above the sill or plank, the flow of water may be calculated with pretty accurate results. For convenience it is well to make the check some even number of feet in width, and bearing some given proportion

to the clear width of the river at that point, so that, by referring to the subjoined table, an accurate total may be arrived at. This table assumes the check to be one foot wide, and the river at this point two feet, so that the check is half of the river. The flow over any size of check can be got by multiplying the tabular flow by the length of check. To make the table strictly applicable, the check should be half as wide as the stream.

Table of Discharges over a check 1′—0″ long.

Dip in Inches.	Cubic feet per minute.	Gallons per day.
⅛ inch.	·2118	1,906
¼ ,,	·5990	5,391
⅜ ,,	1·1004	9,903
½ ,,	1·6492	14,843
⅝ ,,	2·3677	21,309
¾ ,,	3·1124	28,011
⅞ ,,	3·9222	35,299
1 ,,	4·7917	43,125
1¼ ,,	6·7180	60,462
1½ ,,	8·8310	79,479
1¾ ,,	11·1285	100,156
2 ,,	13·5970	122,373
2¼ ,,	16·2235	146,011
2½ ,,	19·0010	171,009
2¾ ,,	21·9215	197,293
3 ,,	24·9780	220,802
3¼ ,,	28·1640	253,476
3½ ,,	31·4755	283,279
3¾ ,,	34·8075	313,267
4 ,,	38·3360	345,024
4½ ,,	45·8870	412,983
5 ,,	53·5630	482,067
5½ ,,	61·8020	556,208
6 ,,	70·4280	633,852
7 ,,	88·7420	798,678
8 ,,	108·4300	975,870
9 ,,	129·3850	1,164,465
10 ,,	151·5350	1,363,815
11 ,,	174·8200	1,573,380
12 ,,	199·2000	1,792,800

In referring to the foregoing table, look for the depth taken on the peg in the left hand column and in the middle column will be found the flow in cubic feet per minute, whilst in the right hand column will be found the gallons per day.

As an example, take a check 4′—0″ long in clear, and the river 8′—0″ wide. The peg is dipped and shows 3″ of water passing over the check. The table gives the flow for this depth over a sill 1′—0″ long as 24.978 cubic feet per minute, and this multiplied by the check in question, viz :—4′—0″ gives the required result, which is 100 cubic feet per minute, or 900,000 gallons per day. It may be mentioned that the discharge in cubic feet per minute may be readily converted into gallons per day by multiplying by 9,000. Thus, a flow of 7½ cubic feet per minute=7·5 x 9,000=67,500 gallons per day. This fact is a most useful one, and should be carefully borne in mind.

Small Rivers.

In the case of rivers of good volume, the abstraction of a quantity of water to supply a small town or village will not be a matter of much difficulty, but cases will occur where the river flow becomes so much reduced by a dry season that even a small portion cannot be spared. When this happens, storage for flood waters must be resorted to ; but of this, more hereafter.

Drainage Areas.

The third source from which a supply may be obtained is that of Catchment or Drainage Areas. This is generally resorted to when the quantity required is large. The advantages in this case are, that when a suitable area is available many of the drawbacks are wanting which belong to other sources of supply. On the other hand, large and costly works are frequently required, and the distance of the area from the district to be supplied is often very considerable, rendering necessary the purchase of a considerable amount of land or way leave, and the construction of a conduit or line of main piping. Drainage Areas vary greatly in their character and suitability. As a rule, those which throw off the rain-fall most rapidly are the best, because the quantity of water available for storage is larger and of a better quality, having had less time to become impregnated with solid matters. As has been already mentioned, a hard rock surface will absorb less water than that formed of more porous materials ; consequently a Drainage Area with such a surface should, if possible, be selected. The quantity of rain-fall available for storage purposes will, as already stated,

depend on the character of the area surface. The subjoined table gives fair average results, from a large number of actual cases.

Description of Surface.		Quantity of Total Rain-fall available for Storage.
Granitic and other hard Rocks, steep,	...	100 to 80 per cent.
Sandstone and other Rocks, less hard,	...	80 to 40 ,,
Moorland or Mountain Pasture,	...	80 to 60 ,,
Ordinary Meadow or Pasture, Flat,	...	60 to 40 ,,
Cultivated Land, Flat,	...	40 to 30 ,,
Fissured Rocks, Chalk, and Pervious Gravel,		00 to 00 ,,
Deep Wells. Yield of the total rain-fall about		30 to 20 ,,

To apply this table in actual practice the rain-fall must be gauged in the district proposed to be selected as a Catchment area. This has been fully described already. As an example, suppose an area of 100 acres under examination and its surface almost altogether Mountain Pasture; suppose also that the total annual rain-fall has been ascertained to be 34 inches. By the table we find that the percentage opposite this kind of surface is 80 to 60, of which we take the lowest; then 34 x 60 = 20·4 inches of rain available for storage. Application of the Table.

Average results like the foregoing cannot always, however, be depended on. Hence in every case it is better to gauge the several streams flowing from a district or area and compare the result with the corresponding rain gaugings. To illustrate this by an example :—Suppose a drainage area, as before, of Mountain Pasture, having an extent of 350 statute acres. Now, assuming the rain-fall, as before, we have a total quantity of water available for storage made up as follows:—The area contains 350 acres. Each acre contains 43,560 superficial feet, and on each foot there falls 34 inches of rain, or 2 5-6ths cubic feet. The total rain=350 x 43,560 x 2 5-6ths=43,197,000 cubic feet. Of this gross quantity only ·60 is available; hence the nett quantity will stand at 25,918,200 cubic feet. Rain-fall available.

Again, suppose that the area in question is drained by three or four streams. These are to be carefully gauged over checks as before described. The dips to be taken at regular intervals, so as to get a fair average. Now, sup- Streams flowing off Catchment.

pose these gaugings to represent on the average, say 40 cubic feet per minute. The total annual product of the stream will be 365 days x 24 hrs. x 60 min. x 40 c.f. per minute=21,024,000 cubic feet available for storage. This result varies considerably from the first, but of course it is to be taken in preference to it; because in the one case the result is obtained by the application of a general rule to an individual case, and in the other the result is arrived at as a matter of actual experiment and observation.

Minimum Supply. The next point to be determined in connection with a Drainage Area is whether any water at all will be available during the driest season for daily supply. This is a most important matter, and should be determined with all the accuracy possible by a long continued series of gaugings. Unfortunately, the time required to do the latter is longer than can be afforded by local authorities. The reason for the importance of this point will be readily seen, because the storage required will altogether depend upon it. To show this, suppose the daily required amount for a town to be 100,000 cubic feet, and the minimum flow in the stream only 20,000 in the day. It is obvious the difference must be made up by storage, and the extent and expense of the storage works will generally vary as the difference between the total daily demand and the total daily supply from the stream during the driest season of the year. This amount is frequently stated as the difference between the maximum demand and the minimum supply.

Storage. Having determined this difference as closely as possible, it will then have to be decided how many days' storage will be required to meet this amount. The number of days generally runs between 100 and 180, and where funds are available the larger amount should be aimed at. In deciding on the question of storage and the amount of rain-fall available for such a purpose, it will be wise not to tax the resources of the Drainage Area too highly. In other words, it is not a judicious course to store all the available rain of a district; or, better still, an area should not be selected whose capabilities are so limited that all its water will be required for use. The

amount of water stored from each acre of gathering ground varies in almost every case. Some authorities store one-half of the available water; but no general rule can be laid down, because questions of reserved rights to farmers, houses, and factories are almost sure to arise. A storage of 12 inches of the rain-fall gives 43,560 cubic feet per acre, and for a rough guide, storage may go as far as 50,000 cubic feet per acre, which is equal to an available rain-fall of 13¾ inches.

To illustrate the foregoing observations by an example of a simple case, take the town to be supplied as having a population of 1,000; the supply per head being fixed at 8 gallons. The total daily demand will then be 8,000 gallons. This is equal to a flow of 1 cubic foot per minute. Assume now that a suitable Catchment Area has been prospected, possessing the various requirements, and having an extent of 50 statute acres. Suppose again that, after due allowance has been made for reserved rights, so as to avoid legal difficulties, there remains 6 inches of rain-fall available for town use. The product per acre would then be equal to 21,780 cubic feet. The total quantity available amounts to 1,089,000 cubic feet. As before mentioned, the required daily supply is 1 cubic foot per minute, or 525,600 cubic feet per annum. These figures show an ample margin. It must be remembered, however, that for three or four months in the year there will be no water available, as any that may be flowing in the streams will be fully required for those parties who may have reserved rights. Hence, during this dry period, the town will be entirely dependent on the storage of the surplus winter floods. Taking the storage at 120 days of the required supply, we have a total quantity of water to be stored of 172,800 cubic feet, and for this quantity due accommodation must be provided.

Selection of Areas.

Before concluding this part of the subject, a few observations of a general nature will be of use. In selecting a Catchment Area, or rather a number of them for examination, an ordnance sheet of the locality should be obtained, and by its aid a large amount of useful preliminary information may be acquired. An approximate summit line, or

ridge, can be sketched on the map by the aid of the levels marked on it, and the extent of the area thus determined. The acreage of the district may be roughly ascertained as follows :—Divide the district on the map into squares of three quarters of an inch, and, as on the large ordnance sheets, each of these squares contains 10 statute acres, the total content can be easily made up. On these sheets, the various buildings in a locality are clearly laid down, so that a glance will show whether an area under consideration is free from mills, dwelling-houses, weirs, &c., and an idea can then be formed as to the number of reserved rights which may require attention. These reserved rights are frequently very troublesome obstacles in the way of water supply, and it is often better policy to go further away from a town, at the risk of a considerable length of conduit or piping, than undertake the difficult and expensive task of satisfying the many claimants who are sure to turn up whenever a scheme of water supply is set on foot. Waters which have been run to waste for ages, utterly unused for any purposes, suddenly become invested with great value when an engineer or committee put down a gauge-check. Again, in selecting an area, which is suitable in every respect, an eye should be kept to the future. Towns may increase in population; and when once the value and convenience of a regular supply is experienced, increase is sure to take place in the demand. The history of many towns proves that, had the future been properly looked to, much trouble and expense would have been saved.

CHAP. IV.—DESCRIPTION OF WORKS.

HAVING finally decided on the amount of water required for a town, and the mode by which such supply is to be obtained, the next matter requiring attention are the works by the construction of which the scheme of supply is to be carried into effect. This opens up a very wide field for consideration and inquiry. The two great points to be ever kept in view being efficiency, with a minimum of outlay for either lands, water rights, or works. The due balance between efficiency and economy is a difficult one to strike, and on this point the Committee and their Engineer are sure to have a difference of opinion. Local Boards have frequently to deal with and endeavour to please clamorous ratepayers, who agitate for a supply of water at a rate of nothing in the pound. Many an engineer has to cut down a really good scheme of water supply to bring it within the financial limits of Local Boards; and this is often carried to such an extreme that the Engineer is almost ashamed of the work which claims him as its author. **Efficiency and Outlay.**

As will be easily seen, it is impossible, within reasonable limits, to describe the works required under the many varying circumstances that may occur in actual practice. A general idea only can be given. Taking the same order as was followed in a previous chapter—viz., supplies from Springs, Rivers, and Drainage Areas—a short reference will be made in succession to the various works usually required. **Order of Works.**

To begin, then, with Springs. When these occur on **Appropriation of Springs.**

the surface, and of sufficient quantity in even the driest season to maintain the requisite supply, the first thing requisite is to construct a line of conduction from the Spring to the district to be supplied. This may be done either by means of an open course, or a closed pipe or conduit. The former is generally the cheapest to construct, but it generally entails the purchase of lands. The latter, though costing more in itself, can be laid by the purchase of way-leave alone, and when the owners of the land are friendly to the work, it can be often arranged that trespass to the occupiers only will have to be paid for. Everything else being favourable, the most direct route for the line of course or pipe is the best and cheapest. But this seldom occurs in practice. Difficult levels often entail a circuitous course. In many cases, when an open course is settled on, use might be made of the ordinary field gripes or ditches, provided the land passed through be pasture, and the gripes not the receptacles of drainage from dwelling-houses. They are usually large enough, and when the levels are favourable, they would serve the purpose just as well as a more costly channel, and the interference with land rights would thus be reduced to a merely nominal amount. When cultivated or even meadow lands have to be intersected, an open course is generally objectionable, because the surface drainage of the fields is sure to work its way into the course, and carry with it a large quantity of animal and vegetable impurities. In such a case a closed conduit or pipe should be laid down.

Conduits.

Conduits are usually formed of brick or stone, or cast iron piping. Sometimes drain pipes of fire-clay are used, but not so frequently as they might be. For a moderate supply of water, and when the total fall is uniform and not too great, fire-clay piping will be found very suitable. When the fall is not regular, iron piping must be resorted to, but in many cases great expense has been gone to uselessly by laying down iron piping where fire-clay piping would have suited just as well. When possible, lines of close conduit should be laid down along the public roads, which saves land purchase or way-leave, and compensation for entry to repair damage.

Table of the Discharge of Culverts and Pipes.

Head of 2 Feet per Mile.

Diameter of Pipe in inches.		Cubic feet per minute.		Gallons per day.
24·	equal	248·	equal	2,232,000
21·	,,	178·	,,	1,602,000
18·	,,	121·	,,	1,089,000
15·	,,	77·	,,	693,000
12·	,,	44·	,,	896,000
9·	,,	21·4	,,	192,600
8·	,,	15·5	,,	139,500
7·	,,	11·4	,,	102,600
6·	,,	7·7	,,	69,300
5·	,,	4·92	,,	44,280
4·	,,	2·82	,,	25,380
3·	,,	1·37	,,	12,330

Head of 5 Feet per Mile.

21·	equal	281·	equal	2,529,000
18·	,,	191·	,,	1,719,000
15·	,,	121·	,,	1,089,000
12·	,,	69·	,,	621,000
9·	,,	34·	,,	306,000
8·	,,	24·5	,,	220,500
7·	,,	18·0	,,	162,000
6·	,,	12·25	,,	110,250
5·	,,	7·78	,,	70,020
4·	,,	4·45	,,	40,050
3·	,,	2·17	,,	19,530

Head of 10 Feet per Mile.

18·	equal	271·	equal	2,439,000
15·	,,	171·	,,	1,539,000
12·	,,	98·	,,	882,000
9·	,,	47·	,,	423,000
8·	,,	34·5	,,	310,500
7·	,,	25·5	,,	229,500
6·	,,	17·3	,,	155,700
5·	,,	11·0	,,	99,000
4·	,,	6·29	,,	56,610
3·	,,	3·07	,,	27,630

Head of 20 Feet per Mile.

15·	equal	243·	equal	2,187,000
12·	,,	159·	,,	1,431,000
9·	,,	68·	,,	612,000

8·	equal	49·	equal	441,000
7·	,,	36·1	,,	324,900
6·	,,	24·5	,,	220,500
5·	,,	15·57	,,	140,130
4·	,,	8·91	,,	80,190
3·	,,	4·32	,,	38,880

HEAD OF 40 FEET PER MILE.

12·	equal	196·	equal	1,764,000
9·	,,	95·	,,	855,000
8·	,,	69·	,,	621,000
7·	,,	51·	,,	459,000
6·	,,	34·7	,,	312,300
5·	,,	22·02	,,	198,180
4·	,,	12·60	,,	113,400
3·	,,	6·14	,,	55,260

HEAD OF 80 FEET PER MILE.

9·	equal	135·	equal	1,215,000
8·	,,	98·	,,	882,000
7·	,,	72·	,,	648,000
6·	,,	49·	,,	441,000
5·	,,	31·132	,,	280,180
4·	,,	17·835	,,	160,515
3·	,,	8·687	,,	78,183

HEAD OF 120 FEET PER MILE.

9·	equal	166·	equal	1,494,000
8·	,,	123·	,,	1,107,000
7·	,,	88·	,,	792,000
6·	,,	60·	,,	540,000
5·	,,	38·	,,	342,000
4·	,,	21·8	,,	196,200
3·	,,	10·64	,,	95,760
2·	,,	3·86	,,	34,740

HEAD OF 160 FEET PER MILE.

8·	equal	142·	equal	1,278,000
7·	,,	102·	,,	918,000
6·	,,	69·	,,	621,000
5·	,,	44·	,,	396,000
4·	,,	25·223	,,	227,007
3·	,,	12·228	,,	110,052
2·	,,	4·469	,,	40,221

HEAD OF 200 FEET PER MILE.

7·	equal	114·	equal	1,026,000
6·	,,	77·7	,,	699,300
5·	,,	49·244	,,	443,160
4·	,,	28·193	,,	253,710
3·	,,	13·732	,,	125,388
2·	,,	4·983	,,	44,847

HEAD OF 300 FEET PER MILE.

6·	equal	95·	equal	855,000
5·	,,	60·3	,,	542,700
4·	,,	34·5	,,	310,500
3·	,,	16·84	,,	151,380
2·	,,	6·103	,,	54,927

HEAD OF 400 FEET PER MILE.

6·	equal	109·8	equal	988,200
5·	,,	69·64	,,	626,760
4·	,,	39·85	,,	358,650
3·	,,	19·42	,,	174,780
2·	,,	7·047	,,	63,423

HEAD OF 500 FEET PER MILE.

6·	equal	122·8	equal	1,105,200
5·	,,	77·86	,,	700,740
4·	,,	44·57	,,	401,130
3·	,,	21·712	,,	195,308
2·	,,	7·879	,,	70,911

Application of the Table.

The foregoing table will be of use in preliminary calculation, and for pipes used as conduits. For pressure pipes it will not apply accurately. Each case of the latter must be considered by itself (see chap. V). In applying this table in practice, one fact must always be borne in mind, and that is—the supply to a town is not consumed regularly; in other words, though the supply can be measured by the day, it cannot be averaged over each hour of the twenty-four. The principal drain on the water service is between the hours of six in the morning and six in the evening, more especially in country towns. Of course in those towns where manufacturing is largely carried on, there is a considerable quantity used during the night. The result of the foregoing is,

that it is unwise to limit the conduit to the size capable of giving only the average demand; and, as a general rule, it is better to use such a size that double the average quantity can be delivered; in other words, that all the water required in a town can be sent down between morning and evening. Other works will generally be required in addition to the conducting pipe or channel; but as their details are very similar in all modes of supply, they will be referred to hereafter.

Well Sinking.

Coming now to the second class of Springs, or those which can only be made available by boring or well sinking, a few words will suffice. When looking for water under such circnmstances, the ordinary course is to sink a well until water is found, and if the latter does not occur a trial is made in another place. The usual authority in such matters is the village pump-maker, who is not averse to well speculation. The wisest course is to test the ground by boring, which gives all the information required, and is, besides, much cheaper than ordinary sinking. Having found water by boring, the bore hole is widened out to a suitable size, and the well lined. This lining is frequently of dry brick work, and when the well is situate in close proximity to buildings, or cultivated land, such a lining is most objectionable, as the well becomes the receptacle for all the surface drainage. It is generally safer, then, to line the well with brick in cement to such a depth that no tainted water can work its way in. Finally, when possible the well should be covered, and at intervals properly cleaned out.

River Supply Works.

Turning now to the second source of supply—viz., that from Rivers or Streams—the first step in the matter of works is to determine the most suitable point in the river at which to draw off the required supply. The conveyance of the water will be exactly the same as that described for Surface Springs. Rivers generally follow the lowest lines of level through a country, so that considerable judgment is required in deciding on the point above mentioned. In many cases a weir is erected in the river bed to raise the water level when required. The pond

thus formed serves to settle the water before it passes into the conducting channel or pipe. Due provision should be made by which, during floods, the supply to the town could be closed, and thus prevent the fouling of the pipes. When the required supply is small, a good plan will be to form an inlet well of masonry in the bank of the river, having an orifice of size sufficient for the admission of the water. The bottom of the well should be considerably below the mouth of the conduit, and by this means the water would be allowed to settle before going into the town. A mud or cleansing pipe should also be put in the bottom of the well to allow of the periodical flushing of the latter. In many cases the river level is too low to allow of any of its waters being lifted and gravitated for town supply. Recourse must then be had to some arrangement for raising the required quantity to a proper height. The best appliance for this purpose is a steam Pumping Engine, the power of which will depend on the quantity of water to be lifted and the total height. The great objection to this arrangement is the constant annual charge required for working expenses, such as wages and coal. In some places where the river is large with a rapid fall, water-wheels of various kinds are used to raise the water. These are worked by the river water, variously applied, but the aim of all is the same—viz., to raise a small quantity of water for a considerable height by the power of a large body of water, having a small fall. Such a mode of raising water has been adopted at the Cork Water Works, where the supply is taken from the River Lee, and pumped up to a high service reservoir. On the water being raised to a proper height into a reservoir or chamber, it is allowed to flow by gravity in the ordinary way to the district to be supplied. In all cases where a river supply is decided on, the point of abstraction should be fixed as far as possible from the district to be supplied. Water taken from a river is always purer the nearer the source it can be obtained.

Storage Works

The last in the list of sources of supply, viz., Drainage Areas, now comes for consideration, and in this department large sums of money are frequently expended on Storage

Works. Having definitely settled on a Catchment Area, the first thing is to determine the amount of storage. This has been already explained. The usual mode of storing water is by the construction of a Reservoir of such capacity as the circumstances of the case demands. In fixing the site of the Reservoir, great care and judgment must be exercised. The primary point being to fix on such a position that the whole of the surface water may be impounded in the Reservoir; or, in other words, the lowest possible part of the Catchment Area must be selected. Economically speaking, the most favourable situation for a Reservoir will be determined by the proximity of materials required in its construction, and by the possibility of using a minimum of materials and still securing a maximum of storage room. Storage Reservoirs are almost invariably formed in this country by earthen embankments; in fact it frequently happens that the making of the embankments, or banks, as they are often termed, constitutes the whole work. From this it will be seen that the most favourable case occurs when an embankment can be thrown across a narrow valley or gorge, having shoulders or wings projecting almost to meet each other, whilst at the same time, the enclosed space is large. The least favourable case is when the Reservoir has to be excavated out of the solid ground, and the resulting material formed into a bank all round. These extreme conditions do not often occur in practice, but the first should always be sought for, and the last as carefully avoided. Compromises have to be accepted in many cases from necessity, but careful examination of the ground and tentative designing will generally give good financial results. The line of a bank cannot be fixed on arbitrary principles, and the Engineer will find that it is only after many failures and disappointments that he gets really a good line of bank laid out.

Cost of Storage.

The cost of storing large quantities of water varies greatly, depending, as it does, on so many circumstances of a local character. Each individual case must be estimated separately. It is usual, however, in preliminary inquiries, to form a rough estimate by comparison with similar work actually executed. The cost is usually put at a price per

million gallons of storage. The following instances will serve as an illustration :—

Crowden Reservoir, Manchester:	Cost per million gallons.		£90	0	0
Armfield ,,	,,	,,	70	0	0
Longindale ,,	,,	,,	11	15	0
Spade Mill ,,	Preston,	,,	43	0	0
Knovel Green,	,,	,,	98	0	0
Upper South Woodburn, Belfast,		,,	67	0	0
Dorisland,	,,	,,	250	0	0
Reservoirs of medium sizes for mill purposes,		from	50	0	0
Designed by the author,		to	30	0	0

A rough average may be formed from the foregoing cases of, say £80 per million gallons storage under ordinary favourable circumstances, but where a Reservoir has to be formed in a position naturally unfavourable, the cost may go up to £400 per million gallons.

Embankments

Having settled upon the site of the Bank, the next matter for consideration is its construction, but as this belongs entirely to the Engineer, a few details only need be given. Banks are formed with slopes on both sides, that exposed to the water being the flattest. The reason for this is that clay, when saturated, takes a flatter angle of stability than when dry. In usual practice, the inner slope, as that next the water is called, is made 3 horizontal to 1 vertical, and the outer slope 2 to 1. In some cases, both slopes are made 2¼ to 1, whilst in the case of low banks, both slopes are made 2 to 1. Many instances are met with where banks have stood well with steeper slopes than the foregoing, but any saving in this respect is at the risk of stability. In the North of Ireland many mill dams have stood well with slopes of 1½ to 1. However, this may be explained by the fact that they were made with good materials, and had great care bestowed upon them during formation. To make a bank water-tight, a puddle wall is generally formed in the centre, extending from top bank level to such a depth below the ground as will ensure its perfect connection with an impervious stratum of clay or rock. Sometimes the puddle is laid on the inner slope of the bank instead of being put in the centre. This mode has

the advantage of being easily repaired; but against this there is the serious drawback that the whole surface of the puddle is exposed to the full pressure of the water, and any crack or flaw is sure to lead the water into the heart of the bank. In the case of the puddle-wall the water is almost entirely deprived of its destructive power before it reaches the wall. General rules for the design of a bank, as derived from good practice, are frequently laid down, but the safest course is to use them only so far as local pecularities will permit. Each case should be determined on its own merits, and this only after a careful examination has been made of the materials to be used. The following, however, may prove of some service. The greatest depth of filling required is found from the bank section. This is termed the greatest height of bank. Then for medium banks the top width may be from $\frac{1}{4}$ to $\frac{1}{3}$ of the height, but never actually less than 8′—0,″ so that a cart can go on it if required. The slopes to be as above. The puddle-wall at top bank level to be from $\frac{1}{4}$ to $\frac{1}{8}$ of the height, but never actually less than 4′—0″. The sides of the wall to have a batter or slope to the ground line of about 1 inch per foot on both sides, and underground, if the depth is not great, the sides may converge with a batter of 2 inches per foot on both sides. Take, for example, a medium-sized bank, having a maximum height of say, 30′—0″, $\frac{1}{4}$th of this gives $7\frac{1}{2}$ feet, and $\frac{1}{3}$rd gives 10 feet. We, therefore, may say from 8 to 10 feet for the top width. The slopes may be 2 to 1 on the outside, and $2\frac{1}{2}$ to 1 on the inner side. The top width of puddle-wall may be from $7\frac{1}{2}$ to 4 feet, according to the character of clay. If it be of inferior quality, the larger width should be taken. These dimensions are given as a rough guide only, but a careful consideration of the local circumstances will serve the Engineer in such cases. In forming a Bank, the materials used are generally assorted, the most adhesive clay going into the puddle-wall, the second quality going to the inside of the puddle, and the inferior materials going to the outside. The inner slope of the Bank is usually protected by a layer of stone, pitching or beaching. The thickness of the stone will vary from 9″ to 24″, according to the height of Bank.

The portion of slope from top water to top Bank should be thicker than the rest, because it is there that the waves have most effect. The top of the Bank and outer slope are usually soiled to a depth of 9″ and sown with grass-seed, so as to form a turf. The level of top Bank should always be at least 3′—0″ above top water: and when the Reservoir has a large acreage, and is exposed to winds, as Reservoirs generally are, a greater height should be given. The usual height for medium Reservoirs is 4′—0″. In forming a Bank, the filling should be deposited in layers of a thickness varying from 1′—6″ to 3′—0″. These layers should have a falling rake towards the puddle-wall, so as to prevent any tendency to slide from it. Before depositing any filling, the surface of the ground forming the seat of the Bank should be stripped of its coating of soil, and all roots or moss thoroughly cleared off; the seat should also be furrowed up longitudinally, so as to key the bottom layer to the natural ground. Where suitable materials can be found within the bed of the Reservoir, they should be used in forming the Bank, and, if possible, and safe, the requisite excavation should be made between top water line and the level of the outlet, thus increasing the water space. Excavation should not be permitted close to the toe of the Bank. Slips come soon enough without being encouraged.

Reservoir Appendages.

Several subsidiary works or appendages are required in the completion of a Reservoir. These include the inlet and outlet, and the waste weir and channel. The first of these usually consist of an arrangement for passing the stream or streams of supply into the Reservoir. Sometimes a weir is put up, by means of which the stream can be turned past the Reservoir during floods, so that the water may not be fouled. Where this is done, a channel must be formed round the Reservoir to pass the water into the stream and below the bank. The outlet may be formed of cast iron pipes laid under or through the Bank, or it may consist of a culvert large enough to contain the pipes and admit of their examination and repair. Another method is to drive a tunnel through the solid ground quite under the Bank or towards its end. This arrangement, though more costly, is the best

and safest. Only in the case of low Banks should pipes be laid through the filling. All filled materials will settle more or less, and this settlement is almost sure to injure some of the joints of the piping, and thus allow the leakage of water into the heart of the Bank. Very many of the failures of Embankments which have occurred are due to the leakage of water from the outlet pipe. This leakage will, in the course of time, cause a vacuity in the Bank, and this in its turn produces settlement. Where outlet pipes are used, they should be bedded in the solid ground, and the track filled with puddle and rammed closely. This will tend to prevent breakage of the joints and the consequent leakage. The egress of water is regulated by a valve or valves. These are sometimes worked by rods from the top Bank, but in large Reservoirs the valves are set in a stand pipe of cast iron. This stand pipe is carried up from outlet level to that of top Bank, and is enclosed in a masonry wall or tower. The valves are spaced at different levels, so that the surface-water may be available, no matter at what level it may be. The valve rods are brought up to the top of the tower, where they are easily accessible.

The waste weir or overfall is provided to allow the escape of the surplus or flood waters. The crest of the weir is set to top water level, so that, when the water reaches this level, the surplus flows over the weir, and passes through the waste channel into the original river bed, below the Reservoir. The length of the weir must be such that it will pass the greatest flood that will occur. A rough guess can be made by an examination of the stream bed above the Reservoir, but the surest way is to calculate the greatest fall of rain for a day, which multiplied into the acreage of the drainage area, gives the greatest flood that may be expected. The table of discharges on Sills will be found of use in the calculation of the length of the weir. As an example, to determine the length of waste weir for a Reservoir, whose drainage area is 300 acres, it may be safely assumed that $1\frac{1}{2}$ inches of rainfall will be the greatest that will take place in 12 hours. This gives 5,445 cubic ft. per acre, and a total of 1,633,500 cubic feet for the whole area.

The weir must thus be capable of passing this quantity in 12 hours. It may be assumed, then, that it will be safe to allow the flood to rise one foot above top water. Now, on looking at the Table page, we find that a sill one foot long, with a dip of 12 inches, gives a flow of 199·2 cubic feet per minute, or 143,424 cubic feet in 12 hours; then, dividing this into the total water to be passed, we have the length of waste weir in feet as a quotient—11⅓ feet. In mountainous districts the rain runs off the land very rapidly, sometimes at the rate of 10 cubic feet per acre. In such a case the waste weir just mentioned would require a length of about 15 feet.

The conveyance of the water from the Reservoir outlet to the district of supply may be by a closed conduit or an open course, as already described.

Summary. A brief sketch has now been given of the usual works required for the storage and conveyance of water. Details have been omitted to a great extent, for reasons previously mentioned. In a work like the present, they are unnecessary. In the actual carrying out of the works too much care cannot be exercised in the workmanship. Many of the mishaps that have happened Reservoir Banks may be traced to bad work rather than to defective design. Public Boards often fall into the mistake of saving the expense of efficient supervision at the risk of the safety of their works. The constant attention of qualified inspectors is absolutely necessary, and without this, the best Engineering skill may turn out a failure.

CHAP. V.—DISTRIBUTION.

Service Reservoirs.

HAVING completed all the required works of storage and conveyance, the next point to be considered is the distribution of the water to the consumers, and on this important subject a few details will be given. When the town is of any considerable size, a Service Reservoir, as it is termed, is generally constructed, as mentioned in a previous chapter. This Reservoir usually contains from one to six days' supply. Being within the influence of a town atmosphere, and other sources of pollution, it should be covered over. The larger class of Service Reservoirs are generally roofed in with brick arches carried on piers, but, in the case of small ones, a wooden cover is usually adopted. They are then called Tanks. The principal objects served by a Reservoir or Tank, are, first, the water is allowed to settle after its passage through the supply conduit or pipe; second, should any mishap befall the latter, the supply can be maintained without interruption during the repair of the conduit; third, the conduit need not be so large as would be required even if connected directly with the town mains. This will at once be seen by taking into account the fact that nearly all the water consumed in any town is used in about half of the 24 hours. Hence, were the conduit and town piping directly connected, the former would require to be of such a size as to pass the full quantity in 12 hours. By using a Reservoir or Tank, containing at least 12 hours' supply, the balance between the supply and demand is preserved.

The conduit may be made to pass only the average quantity, and, during the night, the inflow is constant, and the Tank is then full in the morning to meet the day's demand. In the case of small towns, the Service Reservoir generally takes the form of a Tank of wood or brickwork, and a portion of the Tank is used as a filter. To prevent damage, an overflow pipe must be provided for the Service Reservoir or Tank. Its size can be easily determined by that of the Inflow Culvert, and the quantity of water the latter passes. The discharge of the overflow should be into the nearest sewer or stream bed. A sludge or cleansing pipe should also be provided and connected with a sewer, and by this means a Reservoir or Tank can be cleared out at suitable intervals. Attention to this particular will save much subsequent trouble and expense in the way of cleaning out the main piping. As an example of a Service Tank, take the case of a town having a population of 1,000, and the supply fixed at 10 gallons per head. The total day's supply would then be 10,000 gallons. The Tank then being intended to hold a day's water, would require to be capable of containing the above quantity, which is equal to 1603 cubic feet nearly. The width and length being assumed at 8 feet and 18 feet respectively, the depth of Tank to the overflow would then require to be about 11½ feet. Where the Tank is sunk in the solid ground, the enclosing walls should be built in cement to prevent the infilliation of surface water, with its usual burden of organic matter.

Piping.

Having now fixed the site and dimensions of the Service Tank or Reservoir, we come to the important matter of distributing the water to the consumers. This is done by means of piping. The pipes are formally divided into two classes, viz :—Mains and Services. The former are those by which the water is conveyed from point to point; whilst the Services are those by which it is taken from the Mains, and passed directly to the consumer's premises or to fountains. The material almost entirely used at the present time for Mains is cast iron. Wrought iron has been recommended at different times, but it has not come into general use. Cast iron possesses many advantages, as it can be run in

any required form, and of any required weight of metal, according to the pressure it will have to bear. It can also be easily tapped to take the Service Pipes. The largest pipe cast at the present time is about 4 feet 6 inches, and the smallest 1 inch, and between these limits any diameter can be obtained. The smaller bore pipes are cast in lengths of 6 feet, and the larger ones 9 feet. The joints are usually of the spigot and faucet pattern or flange. In the former, the end of the one pipe is enlarged to take in the end of the other; and in the latter, the pipe ends are formed with flanges which butt against each other, and are drawn together by nuts and bolts passed through the flanges. In making an ordinary spigot and faucet joint, the space between the end of the one pipe and enclosing end of the other is filled partly with gasket or hemp and lead, the latter being to the outside. The gasket is put in first and driven well home, the lead is then poured in, and, when cooled, it is tightened into the space for it with a caulking tool and hammer. To make the lead keep its hold the better, the annular space it occupies is made taper with the wide end inside. Another way of making the joint is by turning up the pipe ends true, so as to make them a perfectly tight fit when driven home. This makes a good joint, but it has the drawback of preventing any deviation from a straight line in laying the pipes. On the other hand, the lead joint allows a considerable amount of lateral come and go, so that slight curves may be worked without the introduction of special castings. The quantity of lead required for a joint will vary with the size of the pipe and the pressure to which it will be subject. Flange joints are usually made tight by turning up the bearing surfaces, and covering them before bolting with a coating of red lead and oil. In places where great care is required, a flat ring of India-rubber is introduced between the flanges, and the whole bolted up.

Thickness of Metal in Pipes

The thickness of metal in any pipe is regulated by the greatest head or pressure to which it will be subject. It is usually calculated by means of Formulae having experimental constants introduced. These are too complicated to introduce in the present work, but a table of the usual cast-

ings is subjoined. This is sufficiently accurate for all practical purposes, and will be found of service—

CAST IRON PIPES.

Weight of One Lineal Yard, in cwts., qrs., lbs.

Diameter of Pipe in inches.	Thickness of Metal.	Cwts.	Qrs.	Lbs.
$1\frac{1}{2}$	$\frac{1}{4}$	0	0	21
2	$\frac{1}{4}$	0	1	0
3	$\frac{3}{8}$	0	1	9
3	$\frac{1}{2}$	0	1	23
3	$\frac{5}{8}$	0	2	11
4	$\frac{3}{8}$	0	1	20
4	$\frac{1}{2}$	0	2	10
4	$\frac{5}{8}$	0	3	1
5	$\frac{3}{8}$	0	2	3
5	$\frac{1}{2}$	0	2	25
5	$\frac{5}{8}$	0	3	19
6	$\frac{3}{8}$	0	2	14
6	$\frac{1}{2}$	0	3	12
6	$\frac{5}{8}$	1	0	19
7	$\frac{3}{8}$	0	2	25
7	$\frac{1}{2}$	0	3	26
7	$\frac{5}{8}$	1	1	0
8	$\frac{3}{8}$	0	3	8
8	$\frac{1}{2}$	1	0	13
8	$\frac{5}{8}$	1	2	0
9	$\frac{3}{8}$	0	3	19
9	$\frac{1}{2}$	1	1	0
9	$\frac{5}{8}$	1	2	9
10	$\frac{1}{2}$	1	1	14
10	$\frac{5}{8}$	1	2	27
10	$\frac{3}{4}$	2	0	13
11	$\frac{1}{2}$	1	2	1
11	$\frac{5}{8}$	1	3	17
11	$\frac{3}{4}$	2	1	7
12	$\frac{5}{8}$	2	0	8
12	$\frac{3}{4}$	2	2	1
12	$\frac{7}{8}$	2	3	23

In using the foregoing Table, an allowance must be made of 3 to 5 per cent. additional for the joints. In the case of

pipes with flanges, it is usual to add 1 foot to the length for the two flanges. The thickness of metal will be regulated by the actual head of pressure under which the pipes will be working. The thinner castings being used for the smaller heads.

Testing Pipes.

Cast iron pipes are always tested before leaving the foundry, with a view to detect any flaws likely to produce bursting after they are laid. This test consists of subjecting the pipes to the pressure of water equal to a certain number of pounds per square inch, or, as it is generally expressed, the pressure corresponding to a column of water with a height of so many hundred feet. The pressure generally varies from 300 feet to 600 feet of water, or from 130lbs. per square inch to 260lbs. per square inch. Whilst the pipes are under this pressure, the additional precaution is taken of tapping the metal, for the whole of its length, with a hand hammer of given weight.

Rust Prevention.

The formation of rust in water pipes is one of the drawbacks arising from the use of iron in their construction. It is due to the presence of oxygen in the water, and it has the effect of not only shortening the life of the pipe, but of also affording a rough surface for the accumula tion of sediment from the water. Deposit in the pipes is frequently a source of great trouble, and the rapidity of its formation is generally in proportion to the amount of solid matter contained in the water. An instance may be mentioned which occurred in Torquay, where a main of 9'' diameter and 2,400 yards long was found to discharge only 456,000 gallons per day. The theoretical discharge was 854,000 gallons. A mode of cleansing the pipe by the use of a scraper was resorted to, and, after two applications, the discharge was increased to the theoretical quantity. In this case the main was coated with a considerable amount of solid matter. With a view to the prevention of rust many processes have been suggested and applied, but out of a great number that most in favour at the present time is known as Dr. Angus Smith's patent process. It consists in coating the pipes at a temperature of 300°, with a preparation of pitch and oil. The cost per ton of pipes treated according to this method

does not exceed 7s, and the additional precaution against corrosion is well worth the extra expense.

Mains.

We now come to the fixing of the diameters of the main pipes, and as the efficiency of a water service depends on the capability of the pipes to pass the required quantity of water, great judgment should be exercised in this department of the work. In many of our towns, especially the smaller ones, serious mistakes have been made through pure ignorance. The usual custom has been to regulate the diameters of piping in one town by those of some neighbouring one. What was made for one place would surely do for another. Were all local circumstances the same, comparison might be a safe enough guide, but when the head and length of piping vary, as they generally do, in different localities, nothing could be more fallacious than blind repetition of other work. The discharge of any pipe is dependent on two factors—on the velocity of discharge and the sectional area of the pipe. The velocity in its turn is dependent on the head or total fall and on the length of the pipe. It will thus be seen that any system of piping laid out without due attention being given to these particulars, is certain to be either inefficient or extravagant in first cost.

To begin, then, with the main pipe leading from the Service Reservoir or Tank. This will require to be continued full size until the first branch main is taken off. When this point is reached, the main is reduced in size. It then continues to the next change and so on, until it has reached its minimum diameter. To determine with accuracy the scale of reduction is sometimes a difficult matter, and entails a considerable amount of calculation. It can, however, be approximated with sufficient closeness for most practical purposes. For the method of computing the discharges of pipes of different diameters, and under different heads, the reader must be referred to the chapter on "Hydraulics," where the usual formulæ will be found. The subjoined Table will, however, be of use in deciding on general arrangements. Where the Table does not exactly apply, the nearest case must be selected, and a safe approximation may then be attained.

TABLE OF THE DISCHARGE OF PIPES.

Diameter of Pipe, 2 inches. Length, ¼ Mile.

Head in Feet.	Cubic Feet per Minute.	Gallons per Day.
5	1·643	14,787
10	2·324	20,916
20	3·286	29,574
30	4·025	36,225
40	4·648	41,832
60	5·692	51,228
80	9·575	59,175
100	7·350	66,150

Diameter of Pipe, 3 inches. Length as Before.

5	4·528	40,752
10	6·404	57,636
20	9·057	81,513
30	11·093	99,837
40	12·808	115,272
60	15·687	141,183
80	18·114	163,026

Diameter of Pipe, 4 inches. Length as Before.

5	9·296	83,664
10	13·146	118,314
20	18·592	167,328
30	22·770	204,930
40	26·238	236,142
60	32·202	289,818
80	37·184	334,656

Diameter of Pipe, 5 inches. Length as Before.

5	16·240	146,160
10	22·966	206,694
20	32·479	293,311
30	39·778	358,002
40	45·932	413,388
60	56·254	506,286
80	64·957	584,613

Diameter of Pipe, 6 inches. Length as Before.

5	25·616	230,544
10	36·227	326,043
20	51·233	461,097
30	62·747	564,723
40	72·454	652,086

Diameter of Pipe, 7 inches. Length as Before.

Head in Feet.		Cubic Feet per Minute.		Gallons per Day.
5	...	37·660	...	338,940
10	...	53·260	...	479,340
20	...	75·321	...	677,889
30	...	92·249	...	830,241

Diameter of Pipe, 8 inches. Length as Before.

5	...	52·585	...	473,265
10	...	74·367	...	669,303
20	...	105·170	...	946,530
30	...	128·810	...	1,159,290

General Rules for Pipes.

A few general principles may be stated which regulate the discharge of long pipes ; they can be easily remembered, and will prove of service. When the diameter of the pipe and its length are constant, the discharge varies directly as the square root of the head ; thus, if it be required to double the discharge of a pipe, but keeping the diameter and length the same, the head must be increased four times.

Again, where the head and length are constant, the discharge varies directly as the square root of the fifth power of the diameter. Thus, in the case of two pipes having the same head and length, but with diameter of 3 inches and 4 inches respectively, the discharges will be as the square roots of the fifth powers of these diameters, or as 15·59 is to 32·0 ; or, in other words, everything else being equal, a 4-inch pipe will discharge fully double the quantity of water passed by a 3-inch pipe.

When the discharge and length are constant, the head will be inversely as the fifth power of the diameter. Thus, for diameters in the ratios, 1, 2, and 4, the heads will be in the ratios of the fifth powers of 4, 2, and 1.

When the head and diameter are constant, the discharge will be inversely as the square root of the length. Thus, for lengths in the ratios, 1, 2, and 4, the discharge will be as the square roots of 4, 2, and 1.

When the discharge and diameter are constant, the head is as the length. Thus, for lengths in the ratios, 1, 2, and 3, the heads will also be as 1, 2, and 3.

By using these principles, and applying them to the Table of Discharges, the latter may be made applicable to any case that is likely to occur. One very general error must be guarded against, and it is simply the rule which is used and followed by many practical men, viz:—That, when all other things are the same, the discharge from a pipe will be as the sectional area. For example, it is very frequently assumed that, with the same head and length, two 3-inch pipes will discharge more water than one 4-inch, because the united area of the 3-inch pipes=14·137 square inches as against the area of the 4-inch which is only=12·566 square inches. It has been shown already that a 4-inch pipe will discharge more than twice as much as a 3-inch. This erroneous method of procedure has done a great amount of harm, and much of the inefficiency and enfeeblement which we find in the water service of many towns are directly due to it.

Branch Mains. After the main piping has been determined by the required discharge, a second class of pipes called Secondary or Branch Mains come up for consideration. These are connected with the Mains, and convey the water to those districts and streets more remote from the leading lines. The proper diameter for these pipes is determined in the same manner as for larger ones. The following example will illustrate the usual mode of proceeding:—To begin, then, at the point farthest from the main, assume a street of say, fifty houses, occupied by working people, the number of persons in each house being five, and the water allowed to each person being 6 gallons. Each house would then get 30 gallons per day, and the whole street would require 1,500 gallons per day. Consequently, a pipe of suitable size for this delivery must be laid down. We now reach a second street containing say forty houses of a better class than the former. The supply per head per day will be larger in this case, say 10 gallons, or 50 gallons per house. The whole street will thus require 2,000 gallons per day. Hence, the pipe in the second street must be capable of discharging 2,000 gallons to its own consumers, and passing 1,500 gallons to the first street. Taking again a third street

which will require a total supply of say 2,500 gallons, the pipe laid in it will be required to deliver this quantity, and also pass the supplies to the first and second streets. Putting these results in a tabular form, they stand as follows :—

Third street Pipe must discharge	6,000 galls. per day.	
Second street	,,	3,500 ,,
First street	,,	1,500 ,,

Assuming that the pipe entering the third street joins the main, and that from the point of junction a second series of pipes branch off in another direction to supply a fourth, fifth, and sixth streets, we arrange the quantities required for these streets in the same manner as before. Suppose that the sixth street will require, say 14,000 gallons per day, the fifth street, say 13,000 gallons, and the fourth street, say 16,000 gallons, the piping must be arranged as before.

Sixth street Pipe must pass		14,000 gallons per day.
Fifth street	,,	27,000 ,,
Fourth street	,,	43,000 ,,

It will thus be evident that the main pipe must be capable of passing 43,000 + 6,000 = 49,000 gallons per day, which is, in fact, the total supply to the town under consideration. One fact, which has been already mentioned, must be clearly borne in mind—that the supply, though stated at so much per day, will be consumed in 12 hours at the most. Some authorities consider that the piping in a town should be so arranged as to pass all the water required in 4 hours. In the general run of small country towns, it will, however, be sufficient to allow for the consumption taking place in 12 hours, and the proper sizes of pipes must be selected accordingly.

To complete the system of piping in the town which has been supposed, we must return to the main. Let its length, from the Service Tank to the point of junction with the branches, be, say a quarter of a mile, with a total fall in this distance of, say 20 feet. We now look in the Table of Discharges for a pipe capable of passing 98,000 gallons per day, with the above head and length. We find the nearest size for our purpose to be a 4-inch. Its discharge is in

excess of that required, but a 3-inch pipe would be too small, and we, therefore, take that erring on the safe side. We thus decide that the main pipe, from the Service Reservoir to the point of junction already mentioned, will be 4 inches diameter.

Now, without any calculation, we see that a 2-inch pipe (no smaller size should be used for branch mains in small town) is capable of passing all the water required in first, second, and third street, even though there should be but little fall from the point of junction, provided the total length of the 2-inch pipe does not exceed a quarter of a mile. The other series of piping passing into fourth street has now to be determined. The first length must discharge 43,000 gallons in 12 hours. If the length be under a quarter of a mile, and the head in this length 30 feet, a 3-inch pipe will do, even neglecting the velocity due to the 4-inch main. The pipe through fifth street must be able to pass 27,000 gallons in the 12 hours; and, on referring to the Table, we find that, with only a 10 feet head in this street, and the length as before, a 3-inch pipe will still be required. In sixth street we require 14,000 gallons in 12 hours, and, to convey this quantity, with a 20 feet head, a 2-inch pipe will do.

These results, arranged in order, stand as follows:—

Main, from Service Reservoir to point of reduction,	4	inch pipe.
First street	2	,,
Second street	2	,,
Third street	2	,,
Fourth street	3	,,
Fifth street	3	,,
Sixth street	2	,,

In the foregoing arrangements, the velocity of the water entering the smaller pipes from those preceding them has been neglected, but this error is on the side of safety. In nearly all our towns, when the piping has been laid down piecemeal, the opposite error has been fallen into. The mains are generally too small for their work, and the consequence is that, in the more remote districts, the pressure is almost entirely destroyed.

The water is conveyed from the mains to the premises of the consumer by means of service pipes. Where the quantity of water required to be passed through the service pipe is considerable, the latter is tapped or jointed into the main; but, as a rule, instead of using a large number of small pipes directly connected, a large service pipe is taken off the main, and the house services connected with it. For many reasons, this last method is the best. The large service can be laid at the side of the street, close to the houses, thus reducing the lengths of the small services. The amount of interference with the street traffic is also reduced to a minimum, because the putting in and repairs to the house services can be carried on without much excavation in the roadway. There is also good grounds for believing that the actual pressure on the house taps is better preserved, because the reduction of the area from that of the main to that of the house service is more gradual than if the latter were taken directly off the former. **Service Pipes.**

The diameter of a service pipe is regulated by the quantity of water to be passed from the main to the house for the use of which it is laid. The usual mode of calculating the flow of water in pipes, is not generally applicable, the head on the service being entirely due to that on the main. The principle usually made use of, is that stated in page 45, viz., that for long pipes having the same head and length, the discharge will be as the square roots of the fifth powers of their diameters. Suppose, for example, we wish to determine how many 2-inch services we can take off a 5-inch branch main. We find that the square root of the fifth power of $5 = 56$ nearly, and the square root of the fifth power of $2 = 5{\cdot}6$ nearly. Thus, we may take ten 2-inch pipe services off a 5-inch pipe. In the same way we find that a 4-inch pipe will supply thirty-two 1-inch services. The following table shows the number of services of different sizes which may be taken off branch mains:— **Size of Service Pipes.**

TABLE OF SERVICE PIPES.

Diameter of Branch Main.		DIAMETER OF LEAD SERVICES.						
		1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$
		SERVICES TAKEN OFF.						
4	...	32	45	66	104	...	...	...
$3\frac{1}{2}$	...	23	32	47	74	...	...	...
3	...	15	21	32	50	88	...	...
$2\frac{1}{2}$	...	10	14	20	32	56	116	...
2	...	6	8	12	18	32	71	180
$1\frac{1}{2}$	...	3	4	6	9	15	35	88

The foregoing table will be easily understood and applied. Suppose, for example, that a row of small houses is to be supplied with water, there being thirty-five houses in the row. Assuming that a $\frac{3}{8}$-inch service will be sufficient for each house, the total number of such pipes can be supplied by one $1\frac{1}{2}$-inch pipe. In this case, a $1\frac{1}{2}$-inch pipe would be taken off the main, and the $\frac{3}{8}$-inch pipes taken off the $1\frac{1}{2}$-inch pipe. Suppose, again, that there are only twelve houses in the row, and, as has first been seen, one $1\frac{1}{2}$-inch pipe can supply thirty-five $\frac{3}{8}$-inch pipes. Now, on looking at the table, one $1\frac{1}{2}$-inch pipe will supply three 1-inch pipes, so that one 1-inch pipe will supply $\frac{35}{3}$ = say twelve $\frac{3}{8}$-inch pipes.

The next point to be settled is the proper size for house service pipes. This is usually regulated by the class of house to be supplied, or, as it is officially stated, by the valuation. Thus a house containing say from four to six rooms will only require the water in the kitchen or scullery, so that there will only be one tap. The usual size of pipe in this case would be $\frac{3}{8}$-inch. A better class of house, containing from six to ten rooms, will likely have a water closet: and the size of service for this case would be $\frac{1}{2}$-inch, which is capable of supplying two $\frac{3}{8}$-inch pipes. Going up still in the class of houses, we come to those which have baths and kitchen boilers. A further increase in the size of service is required in this case. The usual size is $\frac{5}{8}$-inch pipe, which is shown by the table to be capable of discharging as much as four $\frac{3}{8}$-inch pipes. As a rule, $\frac{5}{8}$-inch pipes

are the smallest in use for house supply; but there is no valid reason why small houses with one tap should not be supplied with ¼-inch pipes. The drawing off the water from the tap would certainly occupy a little longer time, but this is a matter of no great importance. It should be borne in mind, however, that with some water the pipes foul very fast, so that a ¼-inch service would soon get closed up. In such a case the pipe should be laid ⅜-inch, but a ¼-inch tap should be fitted on. Sometimes a row of small houses are supplied by ⅜-inch pipes taken off a ½-inch branch from the main. Were all the taps open at the same moment, the pressure of the water would be entirely destroyed; but the probability is that this will not occur. Consequently the authorities in charge of the water supply in a town take as much advantage as they can of this probability; and, unfortunately for the householders sometimes carry the matter too far. While keeping real efficiency in view, however, the service pipes should be laid as small as possible, and by this means the pressure in the mains is preserved. In many towns the principle of working has been large service pipes and small mains, whilst the very opposite should be the case. Frequently a 3-inch branch main is laid down, and the total number of services taken off are double the discharging capacity of the main. The result of this bad arrangement is want of pressure, which is another name for inefficiency.

TABLE OF THE WEIGHTS OF LEAD SERVICE PIPES.

PER LINEAL FOOT.

Bore of Pipe. Inch.	Common. Lbs.	Medium. Lbs.	Heavy. Lbs.
⅜	1·0	1·17	1·4
½	1·07	1·4	1·6
⅝	1·4	1·6	1·8
¾	1·6	1·8	2·0
1	2·0	2·6	2·8
1¼	3·0	3·7	4·4
1½	4·0	4·7	5·6
2	5·0	6·0	7·0
2¼	7·0	8·6	10·0

Materials for Service Pipes. Service pipes are usually made of wrought iron or lead. The iron pipes are the cheapest, but they corrode very fast and soon wear out. They also have the disadvantage of being too rigid to bend round corners in the way lead pipes can do. The latter can be twisted in any direction, a matter of great convenience when the pipes are being carried through a dwelling house. On the other hand, lead pipes are liable to be acted on by the water, the degree of this action being dependent on the character of the water. The result of this is what is known as "lead poisoning." In spite, however, of this drawback, lead keeps its place as a material for service pipes, and there seems to be no metal so suitable from a mechanical point of view. Of late years a patent has been taken out for preventing the direct contact of the water with the lead of the pipe, by tinning the interior of the latter. This is a perfect preventative to lead poisoning, and is well worth the additional expense in those towns where the water is of such a character as to act energetically upon the lead. The principal difficulty attending the use of the tin-cased pipes was the making good joints. This has, however, been almost removed by recent improvements.

Street Fittings In addition to the main and service piping, a variety of fittings are necessary to make a town supply complete and efficient. In villages and small towns the water is generally supplied to the consumer by means of street fountains, placed in convenient positions. These fountains can be had at a cost of £2 and upwards. The simpler forms consist of a cast iron stand or pillar, with the pipe inside, and fitted with a turn-off cock. The latter is generally made with a balance-weight or spring, so as to shut off the water the moment the hand is removed. The principal points to be sought for in a street fountain are strength, simplicity of parts, and non-liability to get out of repair. They are always more or less subject to bad usage, and, if allowed to get out of repair, they are the source of immense waste of water. Fountains should be placed so that the surplus water may be easily passed into the nearest sewer. For controlling and regulating the supply of water, stop cocks and valves are used. Every branch

main should be fitted with a valve near its point of departure from the main pipe; also every service pipe taken off the branch main should be fitted with a stop cock. The object of this arrangement of valves and stop cocks is to render possible the cutting off the water from given districts, without interfering with its general supply. Economy in the laying down of these appliances is nearly always at the risk of inconvenience to the water consumers. Valves and stop cocks can be had in endless variety and patterns. In towns of a better class, fire plugs are put down at suitable points. Their importance and value need not be dwelt upon further than to say that in every town where water pipes are laid, fire plugs should form part of the system. In the smaller class of towns, the plugs will, of necessity, be connected directly with the mains, or the latter will be continued full size by means of a short branch to the plug. In many cases, where the plugs were an after thought to the pipings, they could not be connected with the mains, owing to the expense and difficulty of making the junctions. When a town is to be piped for the first time, this difficulty does not occur, as proper provision can be made for the plugs. In the case of small towns, where fountains are put up for the use of the inhabitants, it will be advisable to have a fire plug at each fountain. They can be easily found at night in such a position, a matter of great importance where the streets are not lighted with gas. Plugs should also be placed at junctions of streets, so as to be available in different directions. Where the water is supplied under good pressure, all that will be required in using the fire plugs will be a hose, which can be attached directly to the latter. Where valves have been put down in sufficient numbers, they can be made most useful during a fire, for the water can be turned off all the streets save the one where the fire has taken place, and all the available water concentrated on one plug. Meters are only used in those towns where the water is sold for special trade purposes. They are designed to register the quantity of water passing through them in a given time. As a rule, however, the authorities in small towns have no water for sale.

Cost of Water Service.

It would be impossible to estimate the expense of putting water into dwelling houses, without going into a vast amount of detail, which would be quite unsuitable in the present pages. The following instances, however, will give a general idea of the usual outlay on various classes of houses.

COST OF PRIVATE WORKS AVERAGED BY GENERAL BOARD OF HEALTH.

1st Class House,	...	...	£3 13 2
2nd do.,	...	..	2 18 6
3rd do.,	...	...	2 3 3
4th do.,	and Cottages,		0 17 6

COST OF WORKS ACTUALLY EXECUTED—COTTAGES.

Date of Work.	Name of Town.		Cost of Each.	Annual Value.
52	Rugby	6	£1 12 11	£5 10 0
52	Croydon	10	2 0 0	4 0 0
52	Barnard Castle	11	1 18 1⅓	3 2 6
52	Tottenham	6	2 11 10½	10 0 0
76	Belfast		1 5 0	5 0 0

Waste Prevention.

The detection and prevention of waste of water by the default or neglect of the consumer, is one of the most arduous duties of water supply authorities. Of the evils attendant on excessive waste, little need be said. It reduces the pressure in the mains, and renders the whole system inefficient. Waste may arise in a number of ways, sometimes from leakage from the public pipes or fittings, but more frequently it is due to defective private fittings. Small leakages are generally the worst, because they are not easily detected. A large burst in a street pipe is seen at once and made good. One of the most usual sources of waste are water closet cisterns. Unless the apparatus attached to the cistern be of good design and workmanship, waste is certain to occur. In addition to waste which takes place without the direct default of the consumer, there is frequently a considerable amount directly attributable to the latter. When the housewife is of cleanly habits, and imbued with a liking for sanitary reform, the water supply is heavily drawn upon. The water closet cistern, where there is one,

is sometimes left open for hours, and the jaw-tub tap is often put on the constant service system. In all towns a certain amount of waste will occur in spite of every precaution; but in many of the larger ones the waste is something enormous. It is stated that in the month of December, 1874, the total quantity of water sent into the city of Dublin in one day was 13,897,000 gallons. Of this amount 7,266,000 gallons were accounted for as used, and the balance, 6,631,000 gallons, was wasted—the waste in this case reaching the enormous figure of 40 per cent. If the matter were properly looked into, it is probable that other towns would show a large amount of waste; but, as a rule, local authorities are inclined to shut their eyes to the evil. The only really effectual mode by which waste can be reduced to a minimum is by the proper supervision of water apparatus put up by consumers. The detection of faulty appliances is a work of difficulty and unpleasantness. Instructions of a plain and definite character should be issued for the guidance of consumers, and where these are neglected or departed from, no water should be supplied. In most towns of any extent the local authorities insist that every water closet cistern shall be fitted with a service box or waste preventer. These boxes are in reality small cisterns, forming part of or attached to the larger ones, and they are arranged to hold one cleansing charge for the closet. In the ordinary water closet cistern the flushing pipe to the closet is connected directly to the cistern, and is thus exposed to the full pressure of the water. The party using the closet can keep the valve open as long as he wishes, and empty the cistern of its water in a few moments. Ordinary cisterns contain from 50 to 100 gallons, so that the consumer has it within his power to waste a large amount of water. The service boxes just mentioned contain from 1½ to 2 gallons, a quantity sufficient to flush any properly constructed closet; and it is out of the power of the consumer to use more than one charge at a time. This is attained by arranging the valves in the service box so that they cannot be opened together. The inlet valve for passing the water from the large cistern into the service

box is also made much smaller than the outlet valve which sends the water down to the closet. It will thus be seen that when the handle of the closet is lifted, the water in the service box is discharged with great rapidity and force, whilst, at the same moment, the inlet valve is closed, and no water can pass from the large cistern to the service box. On the handle being dropped, the box will begin to fill again, but so slowly that the party lifting the handle will not likely wait to repeat the operation of flushing the closet. A large number of service boxes are now in use in England, where their value as waste preventers is fully understood. In their details, there is a great variety, as nearly every maker has a design of his own, but the object aimed at is the same in all. One obstacle in the way of the introduction of service boxes in small towns, is the cost. The many improvements in their design and make unfortunately have the effect of increasing the price. A cheap and efficient service box can be made for a small extra on the cost of the cistern, by forming in the bottom of the latter a wooden box capable of holding from 1½ to 2 gallons. This box will only require side, end, and top, since it may be set in the corner of the cistern. If the latter be lined with lead, the box can be finished in the same way. The inlet valve should be made in the top of the box, and the outlet in the bottom of the cistern. The same spindle should work both valves, and be carried up to the lever, and the remainder of the apparatus may be the same as in ordinary use. A Waste Preventer of this kind may be fitted to any cistern for the sum of 5/- additional to the cost of cistern.

The following regulations as to water supply are in force in the undermentioned towns, where the constant service system is carried out:—

Derby.—Fittings of all kinds are in accordance with the regulations of the company, and in all respects subject to the inspection of the water officials. Service boxes or waste preventers to water closet cisterns are enforced in all cases. No overflows or waste pipes are allowed to cisterns. The total consumption is about 19 gallons per head per day, including supplies for special purposes. Baths and wash-

houses are charged by meter, at the rate of 3d. per 1000 gallons.

Nottingham.—Water closet cisterns are fitted with service boxes in all cases. Waste pipes are prohibited. All fittings must be executed by an authorized plumber, and be subject in every respect to the approval of the water officials. The consumption averages 17 gallons per head per day. The meter rates average from 6d. to 12d. per 1000 gallons, according to the level supplied. Call books are kept at the water office for complaints, etc.

Norwich.—The consumption for all purposes averages 15 gallons per head per day. The use of service boxes is enforced, and the general regulations are similar to those in Nottingham. Meter rates range from 8d. to 12d. per 1000 Gallons.

Leicester.—All water-closets fitted with service boxes. No waste pipes are allowed. Regulations against the waste of water are strictly enforced. Meter rates range from 5d. to 10d. per 1000 gallons.

Dublin.—No waste pipes are allowed, but warning pipes may be put up. All wooden cisterns must be lined. Service boxes passing 2 gallons at a flush are used in all cisterns for water-closets. All approved fittings are stamped at the corporation stores, before being used.

Waste Detection

The discovery of waste is a matter of considerable difficulty, and the duty is one of the most unpleasant which water officials have to perform. When the waste arises from defective fittings, the only course is to inspect the premises where such defect is suspected; but a large number of houses will often be visited, before the waste is discovered. Hence the great difficulty and expense attending waste detection. Where waste results from a burst in a pipe, the evil is soon discovered, as the water will work its way out to the surface. The best time for detecting waste is either late at night or early in the morning. At such periods, there will be no draught on the service pipes, if the latter and the fittings are in good order. Any water passing through the service pipes will, in all probability, be due to waste.

To detect the motion of the water in the pipes, without entering the consumers' premises, the valve key is put in position, and if there be motion in the pipe to any great amount, the vibration will be transmitted to the key, and may be detected by applying the ear to the latter. This is but a rough method of detection, and it fails entirely when the motion in the pipe is very slow. An improvement on this mode consists in the use of a metallic tube, with an end to rest on the pipe. This tube acts on the same principle as the stethoscope, and it has this advantage over the key that a smaller degree of motion may be detected.

A more certain method of detecting waste has been devised by Mr. Deacon, water works engineer, Liverpool. This consists in the use of a water meter of peculiar construction. The dial on this meter registers the water passing through the pipe, but by an examination of the index hand, the motion of the water can be divided into two kinds, the one being intermittent, and due to the opening and shutting of taps, and the other steady, and generally due to waste. It is stated that by the use of this meter in Liverpool, the gross consumption of water has been greatly reduced, and the greater part of the town is now under a constant supply.

In small towns, the cost of waste detection meters would form an insuperable obstacle to their use; and some simple and portable appliance has yet to be devised for the use of water officials in their search for waste.

The best safeguard against waste, and the consequent loss to the funds of the local authorities, is the selling of the water by measurement. This is done by passing the supply to the consumer through a meter which consists of an arrangement of mechanism of such a character that the quantity of water passing through is recorded. The motion of the water drives a train of clockwork, and the latter moves an index arm which points out on a dial the number of gallons passed through. There are various designs of meters to choose from, but the aim of all is the same, viz., to record, in an accurate manner, the quantity of water actually passed through to the consumer. The immediate

result of the use of meters is that the consumer looks very closely after the state of his fittings, and does all he can to check waste of water, because the cost of the waste comes out of his own pocket, and not out of that of his fellow-ratepayers. Unfortunately, the cost of water meters renders their use impossible, except in the case of large consumers. Still, there does not seem to be any good reason why better class houses should not be supplied by meter in the same way as manufactories. Were the supply conducted in this way, the saving of water would be enormous in a town of even moderate size. The meter rent would prove but a small burden to the householders, and they would have the satisfaction of knowing that the amount of their annual water tax would greatly depend on their care. The greatest portion of the waste occurring in any town takes place in the bath-rooms and water-closets of the wealthier classes. In the case of gas supply, the actual consumption is the basis for assessment, but in most of our towns, the working classes, besides paying for the water consumed in their own houses, have to bear their share in the cost of the waste in the dwellings of their richer townsmen.

Considerable care must be exercised in using water meters. With fair play, and regular testing and repair, they give really accurate results. Such results, can, however, only be attained by attention to the following particulars. A meter should be selected of proper size for its work. It should be so situated as to be subject as little as possible to great variations of pressure. A jumping pressure on the meter will interfere greatly with its accuracy. Meters should be tested at regular intervals, and for this purpose two standard duplicates of each size in use should be kept in stock, with which to compare all those brought in for test. The smaller sizes of meters are usually tested by running water through them, and passing it into a tank of known capacity. For the larger sizes, however, this method is inconvenient, and the most accurate plan will be to run the water as it emerges from the meter, over a gauge check, then note the time exactly when the test begins and ends, and the total quantity of water which has passed over the

check can be calculated. The reading of the meter should then be taken, and the results compared.

Supervision of Distribution.

The proper supervision of the distribution of water throughout a town, and the necessary fittings, is a matter of very considerable difficulty, and it is generally looked forward to by local boards with apprehension. Fittings of a cheap and inferior character always give more trouble than those of a better class. Exercising a little care at the outset will save a great deal of trouble in the future. Local boards should therefore draw up specific regulations for the guidance of parties taking in water, and by strictly enforcing these regulations from the commencement of operations, consumers will be led to understand that ordinary economy must be exercised.

CHAP. VI.—QUALITY OF WATER.

AN important inquiry, in selecting a mode of supply, should be the quality of the water which such a supply will afford. It often occurs that a scheme in every other respect suitable must be condemned on this ground. In this department, the engineer must be guided greatly by the chemist. It is not intended in this chapter to go into the question of water analysis, strictly speaking, but merely to give a general outline of the evils to be avoided, and, when possible, to suggest simple tests which may be applied by any person, without a knowledge of chemistry or chemical apparatus. It is not to be understood that these tests are to stand in place of an accurate analysis—by no means; they are merely put forward with a view to prevent loss of time and expense which are frequently incurred in the analysis of unsuitable waters. It is a useless expenditure of money to send samples of water for test, which can be proved on the spot to be polluted, or which exhibit constituents rendering them unsuitable for domestic use. **Suitability of Water.**

Water is seldom, if ever, found perfectly pure in nature. Even rain water has been shown, on careful test, to contain foreign matters to a certain amount. But it will be easily seen that on reaching and penetrating the earth's surface, the number and quantity of these matters will be largely increased. The nature of the ground passed through or over by the rain water will serve as a guide to the character **Rain Water.**

of the foreign matters found in it; and, in the same way, the duration of the contact of the water with the ground will give a comparative value for the amount of these matters.

Impurity in general. The impurity of water, as it is generally termed, is caused by the presence in it of matter, either in the solid or gaseous state. The solid matters may be either organic or inorganic, whilst the gases in the water are generally derived from the combination of the solids with each other, or with the water. Solid matters are found in water in two conditions,—firstly, in a state of mechanical mixture or suspension; and, secondly, in a state of chemical combination, or solution, as it is technically termed. Muddy water is an example of the first state, because, on the water being filtered, or allowed to settle, the solid matter will take the form of sediment, and the water become clear. Sea water is an example of the second form of impurity, for neither filtration nor settlement will remove its contained salts. It will be seen from this that it is a matter of great importance to know the form in which water is polluted, whether mechanically or chemically. The purification of water mechanically polluted is extremely easy, and only requires time; whilst, on the other hand, the removal of impurities chemically combined with the water, is in most cases difficult, and, in fact, impracticable when the water is intended for public supply. Hence, water found chemically impure to a serious extent must be rejected.

Hardness of Water. The presence in water of different matters produces different effects. These effects are, of course, of varying amount and character. One important result, due to the presence of certain foreign matters in water, is that known as "hardness." Pure rain water is the softest water found in nature, and its solvent power is, of course, a maximum in value. Departure from this standard is usually termed "hardness," and the amount of such departure is termed "degrees of hardness." The solvent power of water is one of the principal advantages resulting from its use, and in proportion as a water rises in the scale of hardness, so does it become unsuitable for many domestic uses. The late

Dr. Clark, who fully investigated this subject, formed an empirical scale of degrees, by which to indicate hardness of water. The mode by which this scale is formed is by determining the quantity of lime in a given measure of water. Thus, water of 1° of hardness means that the water contains one grain of lime to the gallon, and water of 2° of hardness means that the water contains two grains of lime, and so on in proportion, ascending in this scale. Water of from 1° to 6° is considered soft; water from 6° to 9° is considered medium; and water from 9° and upwards is considered hard. The actual testing of water to fix the amount of its hardness, is too difficult for ordinary persons, but several samples of water may have their comparative hardness fixed by a simple process which will be described. Hardness is of two kinds—temporary and permanent. The first condition is due to the presence in the water of earthy carbonates, whilst the second is due to the presence of earthy sulphates. Boiling will remove temporary hardness, but it is inoperative in the case of permanent hardness. Thus, water rendered hard from the presence in it of carbonate of lime may be softened by boiling, which precipitates or throws down the lime as a sediment; but when the hardness is due to sulphate of lime, boiling is ineffectual, and the hardness cannot be removed by any method of a simple character. Hence, waters permanently hard should be rejected for the supply of a town. Temporary hardness is not so objectionable; but when moderately soft water can be obtained, it should be preferred. The principal substances found in water, and producing temporary hardness, are the Carbonates of Lime, Magnesia, &c. The principal substances producing permanent hardness are the Sulphates of Lime, Magnesia, &c.

Test for Hardness.

For a positive analysis, showing the degrees of hardness of a sample of water, resort must be had to a proper authority. A comparative idea of several samples may, however, be arrived at, without much trouble. The process is as follows :—A measured quantity of each water to be tested is put into vessels of convenient form—ordinary tumblers will do. They are then to be numbered

in order. A small bottle is then filled with a strong solution of hot water and soap. A given quantity, say so many drops of the solution, is then poured into each sample of water. The latter is then beaten up in the tumbler with a spoon or fork. Each sample is now allowed to stand for a few minutes, and that one is noted upon which a permanent lather has formed. This water is the softest of all under test. An additional quantity of solution is then poured into the remaining samples, and the whole beaten up as before. They are again allowed to stand, and the sample showing a permanent lather is selected, and set aside. This is the next softest water. The process may be repeated, until the whole series of samples has been tested, and their comparative hardness thus decided. This method of test is, of course, only approximate, but it will be found sufficiently near the truth for most purposes. When the party testing the waters can obtain a sample of known degree of hardness, it is easy to fix those under examination. Rain water may also be used as a guide, and the samples can then be arranged in their order of approach to it.

Table of Hardness of Certain Waters.

Distilled Water,...	0·00
London, Thames, ...	16·50
Manchester, ...	2·00
Dublin, ...	0·00
Belfast, Woodburn, ...	7·77
Do. Whitewell, ...	8·10
Armagh, ...	6·22
Newry, ...	1·25
Greyabbey, Well, ...	27·00

Note.—The Dublin Water is unusually soft, but the statement of hardness is from official sources.

Procuring samples of Water.

It usually falls to the lot of promoters of schemes of water supply to select samples of the waters which may be used, for conveyance to the analyst. Some care is required in this matter, as confusion or carelessness sometimes leads

to serious mistakes. Samples of water are often forwarded without correct description, and the analyst is sometimes led into the mistake of giving wrong names to the samples, and in consequence a good water is condemned, and water of inferior quality put in its place. The first step is to procure the samples in sufficient quantity. This should not be less than a quart. The water should be placed in jars or bottles which have been thoroughly cleansed and well rinsed through with some of the water proposed to be taken. On being filled, the bottles should be corked and sealed, and a label put on before leaving the spot. This label should include the name by which the water is known, the date, the condition of the stream, whether in flood or otherwise, and the name of the person taking the sample. As little time as possible should be allowed to elapse between the filling of the bottles and their despatch to the analyst.

Most authorities consider that, for sanitary purposes, a water analysis is sufficiently full when it exhibits the following particulars :— **Analysis.**

Total Solid Matters.
Chlorine.
Free Ammonia.
Albuminoid Ammonia.
Hardness.

An accurate knowledge of these constituents enables the analyst to advise definitely as to whether a sample of water submitted to him is suitable for domestic use or otherwise.

The amount of solid matters contained in a given water is determined by evaporating a determinate quantity of the water and weighing the residue. The result is usually stated in grains per gallon. This is an exceedingly simple process, but to obtain really accurate results considerable refinement is necessary. This last fact puts the determination of the solids out of the reach of all but experienced manipulators. **Solid Matters.**

The separation of the Total Solids into their several constituents is sometimes necessary, but, as a rule, these

constituents are merely classed under the headings of Mineral and Organic matters. The latter, of course, partaking in some cases of an animal, as well as vegetable, character. The following Table exhibits the Total Solids in a few well-known waters :—

	Total Solids per Gallon.
Distilled Water, ...	0·1 grains.
London Companies, taking supply from Thames,	18·5 ,,
Manchester, ...	4·7 ,,
Glasgow, Loch Katrine, ...	2·3 ,,
River Boyne, ...	22·7 ,,
Belfast, Woodburn, ...	11·2 ,,
,, Whitewell Spring, ...	11·3 ,,
Atlantic Ocean, ...	2688·0 ,,

The question will at once arise as to what amount of solid matters may exist in a water suitable for domestic use. No exact maximum limit can be stated, because much will depend upon the character of the matters making up the Total Solids. Thus the London waters contain 18·5 grains per gallon, but this is composed of carbonate of lime to a large extent. If the latter be deducted, the Total Solids in the London, Manchester, and Glasgow waters would be nearly equal. In the matter of public health, London stands higher than either of the cities just named, and, though not attributing this satisfactory state of things to the character of the London water, still it may be inferred that water containing a high solid residue is not on that account to be condemned as unfit for domestic use. This inference must not, however, be applied in every case, and the character of the residue must be determined before any sound deductions can be drawn. The several waters mentioned in the foregoing Table are considered by good authorities as quite suitable for use, as far as the Total Solids are concerned.

Chlorine. The determination of the amount of Chlorine in water is of importance for several reasons, which will be explained further on. It is generally found in combination with Sodium, and sometimes with other metals of an alkaline character, as well as with Magnesium and Calcium. The

presence of Chlorine is not regarded by good authorities as of much importance on its own account; but it generally suggests the presence in the water of some organic pollution of an animal character. A water may be comparatively free from Chlorine, and yet be unfit for domestic use, owing to the existence of vegetable impurities. Most chemists consider that water which is free from sewage pollution is almost devoid of Chlorine; whilst, on the other hand, sewage water is highly charged with it in the form of common salt. The latter is not injurious in a drinking water when its amount does not exceed proper limits. It will thus be readily seen that the quality of a water should not be made to depend on the presence of Chlorine, but when it is found, further inquiry should be made. It may, therefore, be fairly assumed that the absence of Chlorine in a water is a *prima facie* indication, but that only, of its freedom from sewage taint.

The usual mode of determining the amount of Chlorine in a given sample of water is by the use of a solution of Nitrate of Silver. This solution, on being poured into the water, precipitates the contained Chlorine. A given quantity of the water is used, and the silver solution is prepared of a known strength. The addition of a measured quantity of the latter to the water will precipitate a certain amount of Chlorine. As soon as the precipitate in the water ceases to be formed, the quantity of silver solution poured in is noted, and the Chlorine can thus be calculated as a mere matter of proportion. Several matters of detail, requisite for accuracy in the process, are always resorted to, but they need not be described at length.

Ammonia.

To the analyst, the determination of the ammonia in a water is a matter of primary importance. It is indicative of the organic matter existing in the water. Generally speaking, the free ammonia represents the animal organic pollution, whilst the albuminoid ammonia indicates the vegetable taint. The bad effects following the use of a water polluted with organic matter are now generally recognized, though a good deal more observation and investigation is yet required, before the mode is ascertained by which the pollution in the water acts on the human subject.

Medical men, who generally couple together bad water and epidemics of fever, are regarded as alarmists; but, still, facts are rapidly accumulating which show a suspiciously close connection between tainted water and certain forms of disease. Sewage pollution is one of the greatest sources of danger in water. It finds its way into streams and wells, where its presence is unknown, or quietly ignored, until the district is visited by an epidemic. Vegetable matter in a decaying state is also a source of danger, though not to such an extent as sewage. It occurs at certain seasons of the year, in many streams and wells, even in the open country.

Analysts usually state the amount of ammonia in a sample of water, in "parts per million," as in the annexed table.

		AMMONIA. Free. Parts per million.	AMMONIA. Albuminoid. Parts per million.
London—River Thames at Hampton Court,	July	0·04	0·28
Do. River Lee,	Oct.	0·01	0·04
Do. New River,	Aug.	0·00	0·06
Manchester,	Aug.	0·00	0·07
Glasgow—Loch Katrine,	Oct.	0·00	0·08
Windsor—Well,	June	1·20	0·08
Chatham—Well, deep,	Nov.	·03	0·03
Sewage Water,	Feb.	16·20	0·90

Most waters submitted for test will show a certain amount of ammonia, in one form, or both; and the question at once arises, what is the maximum quantity that should be tolerated in a drinking water, without dread of danger? An exact limiting value for both forms of ammonia cannot be arbitrarily laid down, as the proportions borne to each other have an effect on the combined result on the character of the water for drinking purposes. When the free ammonia exceeds 0·08 parts per million, it is considered as resulting from the fermentation of urea into carbonate of ammonia, and indicates that the water is polluted with urine. It has been remarked that diarrhœa is a frequent visitor in those districts using water which contains from 0·10 to 0·20 parts of albuminoid ammonia per million.

The determination of the ammonia in water is a process of great delicacy and intricacy, and its details would be useless to most readers. It is generally known as the "ammonia process," and the results obtained from it are regarded by analysts as highly trustworthy. A rough method of determining the organic impurity in water was by the ignition of the solid residue. The difference in weight before and after ignition was considered to represent the organic matter which was consumed. For several reasons, this method was inaccurate; and where really correct results are required, the "ammonia process" is adopted.

A number of analyses of samples of water are now submitted, and by a careful comparison of these, a good idea can be formed of what constitutes a fairly pure drinking water.

LONDON WATER SUPPLY—Thames.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
18·5	1·2	16·5°	0·01	0·06

The above water is filtered, and supplied to several districts of the Metropolis. It is considered of fair quality, but hard. The quality is inferior during the winter season, owing to the floods in the river.

MANCHESTER WATER SUPPLY.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
4·7	—	2°	0·01	0·06

The above is collected from moorland and hill pasture, and is considered a good water. Its softness renders it valuable for cleansing purposes.

GLASGOW WATER SUPPLY—Loch Katrine.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
2·3	0·9	—	0·00	0·08

The above water is brought from Loch Katrine, a mountain lake. It is considered a good water.

GUILDFORD WATER SUPPLY.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
19·7	0·9	14·7	0·00	0·01

The above is a remarkably good water. It is above the average in hardness, but it is unusually free from organic impurity.

BELFAST WATER SUPPLY.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
11·2	1·7	$7\frac{7}{9}^\circ$	0·01	0·08

The above water is of good quality, and is collected from hill pasture.

DUBLIN—Vartry Water.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
4·50	—	—	·014	·028

The above water is collected from the Wicklow mountains, and is of excellent quality.

CORK—River Lee.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
5·57	0·661	—	0·571	1·07

This water is pumped up from the River Lee, at a point close to the city. It exhibits evidence of a large amount of pollution.

WATERFORD—Pump Water.

Grains per Gallon.			Parts per Million.	
Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
70·10	13·00	—	57·970	15·712

This water was greatly used in Waterford. It is pronounced by Dr. Cameron to be the worst water ever brought under his notice.

Greyabbey, Co. Down—Well Water.

Grains per Gallon.			Parts per Million.	
Total Solids.	Com. Salt.	Hardness.	Free Am.	Album. Am.
105·1	36·8	27°	0·037	0·084

This water was analysed in consequence of an outbreak of typhoid fever in the locality. Its use was condemned by Dr. Hodges.

Carnlough, Co. Antrim.

Grains per Gallon.			Parts per Million.	
Total Solids.	Com. Salt.	Hardness.	Free Am.	Album. Am.
11·20	2·4	5·5	0·09	0·069

This water was taken from an open mill-race passing through the village of Carnlough. It was analysed for the same reason as was given in the previous case. Its general use was condemned by Dr. Hodges.

A sufficient list of analyses has now been given to guide the reader in forming some general conclusions as to the suitability, or otherwise, of a water under examination. Too much importance must not be laid on the excess, or otherwise, of individual ingredients. An eye must be kept to all the constituents which are set forth in the previous cases. The following example will show the safe limits beyond which the ingredients should not extend. **Summary of Examples.**

Total Solids.	Chlorine.	Hardness.	Free Am.	Album. Am.
		Should not exceed		
Grains per Gallon.			Parts per Million.	
40·	10·	9°	0·04	0·07

It is to be noted, however, that when the free ammonia is less than 0·04, the albuminoid ammonia may be higher than 0·07; as in the case of the Belfast water, in which the free ammonia is 0·01, and the albuminoid ammonia is 0·08.

Though the character of any water may be accurately determined by the analysis just described, it is frequently desirable to carry the analysis still further. In doing so, **Analysis of Total Solids.**

the total solids are first determined. The mode of ascertaining the gross amount of these solids has already been referred to, and the separation of this total into its constituent parts is sometimes resorted to when further information is required. A complete detail of the analytical processes required in this stage would be useless, and is therefore not given. One of the most frequent constituents in the total solids is carbonate of lime, the amount of which in the water is taken as indicative of its hardness (Clark's method). The determination of the question whether sulphates are present in the water, is a matter of considerable importance, because, as has already been explained, the property of permanent hardness is due to the existence of sulphates. This species of hardness cannot be removed or reduced by boiling; and, consequently, a water possessing this quality is quite unsuitable for culinary purposes. The presence of poisonous metals in a water is another matter deserving inquiry. The metals most frequently met with are iron and lead. Fair drinking water should not contain more than 0·20 grains of iron per gallon, nor more than 0·18 grains of lead per gallon. Lead poisoning sometimes occurs by the use of a tainted water; but, in most cases, the lead is absorbed by the water in its passage through service pipes, and it is only occasionally that the lead is found in a natural water.

Effects of Soft and Hard Water.

The majority of authorities are in favour of soft water for domestic use, though some eminent men still hold strongly to the hard water. It is stated in support of the latter view that in most of the large towns where soft water is used, the death rate is higher than in those places which are supplied with hard water. Thus, we find the rate of mortality is considerably greater in Manchester, Glasgow, and Dublin, which are supplied with waters of not more than four degrees of hardness, than in Birmingham, Bristol, Croydon, and London, where the waters are hard. The death rate in the former towns varies from 26 to 34 per thousand, whilst in the latter it varies from 22 to 26.

It is further stated by the advocates of hard water,

that in Continental countries where conscription for the army is in force, more conscripts are rejected in those districts where soft water is used by the inhabitants, than where hard water abounds—the ground of rejection being want of proper physical development.

A further argument is drawn from the fact that hard waters are, generally speaking, much more palatable than those of a softer quality. To a person accustomed to the former, the contrast is extremely great, for the soft water is certainly very flat and tasteless.

On the other hand, it is urged by the advocates of the soft waters, that in those towns where the hard water has been replaced by the soft, the death rate has not increased, but rather the contrary; nor are there any good grounds for assuming that the death rate of London would be increased by the introduction of a supply of soft water.

It is also put forward by the advocates of the soft water, that it is more capable of performing the important part of an assistant to digestion than a hard water. Amongst cattle, it has been frequently observed that they will pass by the clear spring, because its waters are hard, and drink from the muddy pool instead.

A strong argument in favour of a soft water is the great saving of soap which its use ensures. Nothing can be more annoying to the washer-woman than hard water. It simply means a great waste of soap, much additional labour to the person washing, and great wear and tear of the articles being washed. It has been estimated that in Glasgow the saving in soap alone by the introduction of soft water from Loch Katrine, has averaged something like £40,000 per annum.

Effects of Polluted Water on Health.

Most authorities agree in regarding polluted drinking water as a means of communicating certain forms of disease, such as diarrhœa, cholera, and typhoid fever. Professor Wanklyn mentions that in the Leek workhouse there has been for years past a general tendency to diarrhœa, which could not be satisfactorily explained. At length the water was examined, and found to be loaded with vegetable matter. It contained only 0·5 grains per gallon of Chlorine,

but the ammonia stood as follows:—free am. ·02 parts per million, and album. am. ·321 parts per million. Another well some few miles distant from Leek was also found to produce diarrhœa in the persons using it for drinking purposes. Its water contained chlorine 0·5 grains per gallon, free am. 0·03 parts per million, album. am. 0·14 parts per million.

It is a noticeable fact that diarrhœa most frequently prevails in small towns and rural districts during the autumn months. This is usually explained by the incautious indulgence in fruits and vegetable diet at this season; but it should be borne in mind that at this period of the year vegetation has begun to decay, and by the assistance of the autumn rains it finds its way into the streams and watercourses of a district. As a natural consequence, the water becomes polluted with vegetable matter, and it is thus rendered unfit for domestic purposes, though at other seasons of the year its use might not be attended with any evil consequences.

With regard to the influence of bad water during the prevalence of cholera, sanitarians are somewhat divided in opinion. Some believe that the disease may be induced by the use of polluted water, whilst others take a less decided view, and merely go the length of granting that a water actually tainted with the cholera virus will convey the disease. During the last epidemic of cholera in Ireland, Dr. Cameron found that the pump water used in several districts where the disease was most severe, was largely polluted with animal impurities. In the town of Mallow there were few cases of the disease, except in one suburb in which the well water was found to be loaded with organic matter. In those parts of the town where the disease did not prevail, the drinking water was remarkably pure. In a report on the spread of cholera in Holland, M. Ballot states that in every town where rain water was used for drinking purposes, there were either no cases of the disease, or only a few isolated ones. On the other hand, the disease prevailed where the villagers drew their water from wells or canals.

The theory that the general propagation of cholera is

favoured by polluted water has been greatly strengthened by observation in Northern India. Dr. Brydon reports that while the water tanks are fouled by dipping clothes in them, aud by bathing in them, and the supplies drying up, the disease rapidly increases; but when the tanks are cleaned out, and re-filled with pure rain water, the epidemic subsides.

During a late visitation of cholera in the districts surrounding Dundee, Leven, and Musselburgh, it was found that the abatement of the disease was coincident with the closing up of the impure wells in the locality. In a paper read before the Social Science Congress in 1868, Dr. Macadam states, 1st—that in all the towns and villages in Scotland where cholera appeared this winter, and the waters of which have been examined, the water has been found to be unsatisfactory in quality, has been contaminated with sewage matters, and has been more or less unwholesome. 2nd—That the impure water exerts an injurious influence on health, especially when combined with other adjuncts of disease, such as foul air from dirty streets and lanes, confined house accommodation, low diet, and scanty clothing. 3rd—That the introduction of a better water supply into infected districts has proved most beneficial in allaying the severity of attacks of disease, and in staying its progress.

The following general conclusions are stated by M. Ballot, who has been already referred to :—

1st—Our country is highly affected by the cholera at every epidemic, chiefly in those parts where they drink water drawn directly from the rivers and canals, or from the ground saturated with sewerage matter.

2nd—In places where rain water is generally drunk, the disease is by far less violent.

3rd—Places where there is no other drinkable water but rain water, are not affected by the epidemic; the single cases occurring there are imported.

4th—When places affected by the cholera were supplied with pure water, instead of the vitiated water, the disease disappeared.

The exact nature of the connection between typhoid fever and impure drinking water has not yet been determined, though the fact that some such connection does exist, is now generally acknowledged. It is supposed by many that the common cause of typhoid fever is decomposing organic matter, chiefly of a vegetable character. For the conveyance of matter in this state, drinking water forms the most usual vehicle. It has been found in Massachusetts, that the period during which typhoid fever is prevalent coincides with that in which the water is lowest in the wells. Typhoid fever, as a rule, is more general in small towns and villages, than in large cities; and the former are usually supplied with polluted well water. One or two instances have been already given where an epidemic of typhoid fever caused the authorities to suspect the drinking water used in the locality. Analysis of the water showed that it contained elements injurious to health. The following cases have been recorded by Dr. Cameron. A family in Kingstown was attacked by typhoid, and several of the cases ended fatally. The water was examined, and found very bad in quality. It contained large quantities of free and albuminoid ammonia. It was subsequently found that the point of discharge of the water-closet soil pipe was within a yard of the well. Typhoid fever broke out some time ago in one of the departments of the staff of the Board of National Education, Dublin. The water used by the parties affected was examined, and found to be largely polluted with sewage matters. Since the introduction of the Vartry water, for the foul pump water previously used in these departments, no further cases of typhoid have occurred.

It is still a doubtful point whether polluted water actually produces typhoid, or only acts as a carrier. The evidence is so far in favour of the latter view. Dr. Cameron instances a case which came under his own notice. A person went on a visit to a family in Dublin, and he was attacked with typhoid fever, the initial stage of which must have been going on prior to the date of his arrival in Dublin. The patient was most carefully isolated from the

family, but without avail, for in a short time, the disease appeared amongst its members. The well water used by the household was analysed by Dr. Cameron, and found to be loaded with animal impurities. A direct connection was discovered to exist between the well and the house sewer. The inference to be drawn from the foregoing is that, in this instance, decomposing animal matter did not give rise to the typhoid fever, but merely served as a carrier; because, the foul water had been in use for a long period, and yet no case of the disease occurred, until the arrival of a stranger in the household.

It is quite possible that many other diseases besides those mentioned may be communicated by the use of polluted drinking water, but the information on the whole subject is so scant, that nothing definite can be put before the reader. It is believed that scarlatina may be conveyed by poisoned milk, and it may, in like manner, be conveyed by tainted drinking water. Milk and beef cattle have been known to suffer from the use of polluted water, and it is not going too far to infer that the diseases produced in the cattle may be carried into the system of those parties using the milk or beef as food.

Summary.

Quite enough has now been said on the quality of drinking water, to show that the subject is worthy of much greater attention than it receives at the hands of local authorities. There is a great deal yet to be learned before the exact bearing of drinking water upon disease can be clearly explained; but still it is now quite undeniable that pollution in water means disease, and sometimes death, to the consumer. Local authorities may try and shut their eyes to this startling conclusion, but still it stands staring them in the face, and calling upon them to take action.

CHAP. VII.—PURIFYING PROCESSES.

THOUGH every precaution should be taken to secure a really good water for the supply of a town, it seldom happens that this object can be attained in its entirety. Almost always a choice has to be made between a stream water, of a soft character, and perhaps slightly tinged with peat, and liable to be rendered useless during floods, by the amount of mud in suspension,—and a clear spring water, pure in other respects, but posssessing a high degree of hardness. This choice of evils is often forced upon the authorities of small towns and villages, whose means prohibit their bringing in water from a distance. They are, consequently, compelled to select a water near at hand, even though it be objectionable in some particulars.

Filtration.

Many processes might be suggested to remove the impurities found in water, but most of them are impracticable, on the ground of expense. Anything that can be attempted in this direction must be simple and inexpensive, and the only process yet successful and economical has been filtration. This process, generally speaking, removes only mechanical impurities; and it consists simply of a method of passing the water through some filtering medium, sufficiently close to intercept the small particles of impurities, but open enough to allow the free passage of the water. A certain amount of purification can be produced by settlement, because much of the mud and sediment found in water, during floods, will subside as soon as the water assumes a state of rest. Where sufficient time is allowed, a large amount of the mechanical impurities may be got

rid of in this way. Hence, we find, in connection with large towns, extensive works for the settling and filtration of the water, before its distribution to the consumers. Storage reservoirs serve as settling ponds, but where these are not required for their own purpose, some arrangement might be made by which the water may be allowed to deposit its impurities. The usual way, in works of any extent, is to pass the water through a filter bed, after it has had a certain time for settling. The filter is generally composed of several layers of materials, the layers being disposed one above the other, the lowest one being the coarsest, and the upper one the finest. The water is admitted on the upper layer, whence it passes downwards, and then into the main pipe for distribution. The greater part of the actual work is done by the upper or finest layer, and the lower ones merely serve as a pervious support to the upper layer. These layers are generally composed and arranged as follows :—The bottom layer, of broken tiles, stone, or brick, about 2′—0″ thick ; the next, of coarse gravel, 2′—0″ thick ; the next, of fine gravel, 1′—0″ thick ; the next, of coarse sand, 1′—6″ thick ; and the uppermost layer, of fine sand, 2′—0″ thick. This arrangement, may, however, be modified to suit local circumstances, as it is always best to form the filters of materials found close at hand. The quantity of water required to be filtered in the twenty-four hours will, of course, determine the extent or area of the beds. Each square yard of filter will pass a certain amount of water, if kept constantly fed ; and were this quantity always known, it would be a mere matter of calculation to fix the surface of filter wanted. The capability of a bed cannot be determined, however, with any accuracy, by calculation. Actual trial is the only safe guide. A good deal depends on the degree of fineness of the surface materials, the amount of impurity in the water, and the amount of work to be done by the filter before it will be cleansed. It has been found in general practice that one square yard of filter will pass from 500 to 1000 gallons of water in the twenty-four hours, or say, for a rough average, about 750 gallons. Hence, for a town getting a supply of

20,000 gallons per day, the filter bed would require a surface of 27 square yards. In some cases, duplicate filters are provided, so that one can be used at a time, and the other cleansed. The cleansing of a filter bed, such as that described, is an exceedingly simple matter. The surface of the sand is merely pared over to remove the dirt, and the deficiency thus caused renewed from time to time. Many other modes of filtering water have been suggested, but none of them are applicable on a large scale. Hence the ordinary sand filter has held its place as the best, both on account of its cheapness in first construction, and, what is of nearly as much importance, its self-acting character, and non-liability to go out of order. Many large filter beds have been constructed by some of the water companies in London ; but for a detailed description of these, reference must be made to technical works.

Effects of Filtration.

The principal object gained by filtration is the removal from water of its mechanical impurities. The effect in this direction may be roughly stated as follows :—The sediment in the water, whilst passing through the filtering material, attaches itself to the latter, and the water flows downwards. Hence, the finer the materials can be obtained, the more successful will be the filtration, that is, provided a proper time be allowed. It is now established, however, that filtration by sand has some effect on the organic impurities in water. It is stated by one authority that a rough filtration of diluted sewage water will reduce the organic matter from 100 grains to 20 grains per gallon. A finer filtration will still reduce the organic matter to 10 grains per gallon. The following cases will show the effects of the filtration as practised by the London water companies:

THAMES WATER TAKEN NEAR HAMPTON COURT.

	Free Am.	Al. Am.
	Parts per Million.	
Sample No. 1, unfiltered, July, - - - -	0·045	0·28
Sample No. 2, do., - - - -	0·015	0·23
Sample No. 1, passed through Filter Pipes, -	0·045	0·21
Sample No. 2, do., do., - -	0·015	0·185
Water after Filtration, - - - - -	0·01	0·06

It will thus be seen that filtration exerts a most beneficial influence in reducing the amount of what may be termed the dangerous elements in water.

Besides the filtration performed by local authorities on a large scale, consumers are frequently compelled to provide filtering appliances for their own use. This is usually the case in country towns. Many forms of filters are now in use, and there are many others which have never yet got into use. One of the cheapest and most simple is made with a wooden box, having a false bottom, pierced with holes. On this false bottom are placed layers of coarse and fine cinders, and a surface layer of fine sand. The water passes down through the layers, and collects between the two bottoms, from which it can be drained off for use. Filter stones are frequently used, and they serve their purpose well for a short time; but they soon get clogged with dirt, and it is impossible to cleanse them.

Animal charcoal is now acknowledged to be the best material for filtering water. Its action is not confined to mechanical impurities, for it will intercept organic matter brought into contact with it; but, as would be expected, the charcoal will soon become fouled, and require cleansing. The latter may be done by a chemical process, but exposure to the air will serve the same end, if sufficient time be allowed. Slow filtration through a 4-inch layer of animal charcoal in coarse powder will remove nearly all the organic matter in water. Dr. Cameron has reduced the organic matter in a water from 3·4 grains per gallon to 0·2 grains per gallon, by filtration through a 2½-inch layer of charcoal. It is still, however, an open question whether filtration through animal charcoal can effectually remove the germs of typhoid fever, or Asiatic cholera. Dr. Franklin traced the cholera poison, after filtration, in a water previously known to have been tainted with choleraic discharges. Of patterns of charcoal filters, there are a good many to choose from. They are made from the small table size to the tank filter. Several patents for filters have been taken out, and, as might be expected, each design claims superiority. Consumers should see, when purchasing a

filter, that it is simple in arrangement, and that they get animal charcoal, because vegetable charcoal, though much used as a filtering medium, is very much inferior to the other. Every household should be provided with a filter of some kind, for the expense is very small, and the additional purity of the water is well worth the cost.

In addition to the purification of water, by filtration, as just described, there are other methods by which foreign matters in water may be precipitated, or rendered innocuous. Thus, alum is sometimes used to throw down the suspended matters in muddy waters. From 3 to 6 grains of alum to the gallon should be used. Condy's patent solution is used to destroy organic matter in water. It is, however, doubtful whether it acts on the germs of disease contained in the water. Boiling water before use is a necessary precaution during epidemics, or when organic pollution is suspected in the water. It has, however, the drawback of rendering the water insipid in taste. Another result of boiling is the reduction of temporary hardness by the precipitation of the earthy carbonates. This has, however, been already explained.

Dr. Clarke, whose name has been previously referred to, in connection with the "soap test" for the hardness of water, applied himself to devise a method by which hard waters could be softened. In this he succeeded perfectly, and his process has been introduced at the Plumstead Water Works, where it has been in operation for a considerable time. It has been introduced at the Colne Valley Water Works during the present year. The process is based on the principle of expelling chalk by chalk. As already explained, chalk, or carbonate of lime, is one of the principal substances producing hardness in water. Carbonate of lime contains about 9 parts of lime and 7 parts of water. By the well-known process of burning the limestone or carbonate of lime, the carbonic acid is expelled, and a hydrate of lime results. Now, by adding to the hard water, which it is proposed to soften, a certain quantity of this hydrate of lime, mixed with a given proportion of water, almost all the lime contained in the water under treatment combines

with the added lime, and forms bi-carbonate of lime. This is precipitated, and the water is left clear, and almost devoid of lime. Water softened by this process can be reduced from 17½° of hardness to about 1½°. This mode of treatment is the only one known capable of being applied on anything like a large scale; and it is even questioned by some whether the results are worth the trouble and expense which the application of the process must necessarily involve. Water of a moderate degree of hardness can generally be made available, except in the chalk districts, so that a prime object should be to select a water of such an amount of hardness that no softening would be necessary. Dr. Clarke's process, besides precipitating a large portion of the carbonate of lime, possesses the additional advantage of removing a great deal of the organic matter present in the water; and if the latter be coloured, the colouring matter is removed to a very large extent.

The following analyses of water, before and after treatment by Clarke's process, will show the reduction of the organic matter.

	Free Am.	Alb. Am.
	Parts per Million.	
Sample 1, before Clarke's process,	0·01	0·05
Do. after do. do.,	0·01	0·02
Do. 2, before do. do.,	0·025	0·22
Do. after do. do.,	0·030	0·08
Do. 3, before do. do.,	0·15	0·22
Do. after do. do.,	0·020	0·07
Do. 4, before do. do.,	0·195	0·12
Do. after do. do.,	0·15	0·06

As measures of precaution, a few points of detail will now be mentioned which, if attended to, will tend to prevent pollution. Decaying vegetation soon finds its way into streams and water courses, and from these into the rivers of a district. This occurs more particularly during the Autumn months, when leaves are falling. By the employment of gratings in suitable positions, the grosser matters can be collected, and prevented finding their way into supply conduits. When the latter pass through plantations or cultivated lands, they should invariably be

covered. In the case of service reservoirs which are not roofed, surface cleansing pipes should be provided at top water line, and, by their being opened periodically, the scum that collects on the surface of the water could be easily run off. All inlets and other portions of the works likely to collect sediment should be regularly cleaned out. The injurious influence of organic matter is much increased by being allowed to decompose. In some parts of Ireland flax matter is a cause of great trouble and annoyance to the local water authorities. After the flax has been steeped, the contents of the dams are run off into the nearest ditch, from which they find their way into the streams. Any reservoirs or water courses situated in a flax-growing district are sure to get more or less of the flax water, and nothing but constant watchfulness on the part of officials and strict enforcement of the law on the subject will prevent pollution in this respect. In the case of farm-house sewage, every care is taken by many of the farmers to pollute the water passing their houses with it as much as they possibly can. In how many instances do we see the water passing into the farm-yard by a spout, below which there is an open pool or horse pond. In this the farm cattle and poultry perform their ablutions, and, what is worse, the pool receives all the drainage from the stable and cow-house. By the time such water reaches the next farm-house or the main river it is nearly equal in strength to liquid manure.

When streams such as the foregoing are situated in the drainage area of a public reservoir, legal steps should be taken to compel parties to pass all running streams clear of their premises without pollution. A little care in the outset, on the part of local authorities, is all that is required to secure this object. Farmers are not prohibited from drinking dirty water themselves, but they certainly are amenable to the law when they pollute the drinking water upon which their neighbours are dependent.

Chap. VIII.—Hydraulics.

Nature of the Subject.

The science of Hydraulics treats of the laws regulating the flow of water. It is a subject which opens up a very wide field of inquiry, and its investigation has engaged the attention of some of our most able men of science. Its elementary principles have been well known and understood for a considerable time; but, as a strict application of these principles does not give accurate results in actual practice, we are to a great extent dependent on experimentalists for necessary corrections. Several most eminent men have spent their life-time making experiments, and reducing their results to the limits of defined laws. Much has been already done in this way, and many perplexing points cleared up; but still there is great room for further research. As is the case with all branches of experimental physics, many mistakes have been made, but this is not surprising. Experimentalists are frequently in too great a hurry to generalize before they have acquired sufficient data to build upon. The consequence of this has been that many of the writers on Hydraulics differ amongst themselves, and that often to an alarming extent. Of late, however, considerable progress has been made. Experiments have been conducted with greater accuracy than formerly, and the several conditions affecting them have been carefully noted. A complete list of the experiments which have been made from time to time would be too extensive for a work like the present; and it is, therefore, only proposed to give a sketch of what is known on the subject. And though many details are necessarily omitted, it is hoped that all the really important principles of the science will be found in their proper order.

Action of Gravity.

The natural agent which produces motion in water, as in other bodies, is gravity. The action of this agent is fully investigated by the science of Dynamics. The character and amount of motion produced in a given body can be stated accurately in proper formulæ. In Hydraulics these formulæ are made use of, because it is assumed that the motion of water rushing down a mountain side or trickling along a level bed may be properly expressed by them.

Explanation of Terms.

The pressure of water is usually measured in "feet" of water. It is sometimes expressed as a "Head of Pressure." Thus, for example, suppose a surface of one superficial foot, and this surface exposed to the pressure of a column of water 10 feet high. The Head of Pressure is then 10 feet. The weight of a cubic foot of water is usually taken at 62·4 lbs.

The total head of a particle of water is stated by Rankine to be made up of the following :—

The Head of Pressure in feet of water as above, and the Head of Elevation, or height of the particle above some given "datum."

In measuring pressures of water, the atmospheric pressure is not included.

The pressure of the atmosphere at sea level varies from 32 to 35 feet of water.

TABLE OF PRESSURES.

1 foot of water	=	62·4 lbs per	sq. foot	=	0·433 lbs per	sq. inch.
2 feet	,,	124·8	,,		·866	,,
3	,,	187·2	,,		1·299	,,
4	,,	249·6	,,		1·733	,,
5	,,	312·0	,,		2·166	,,
6	,,	374·4	,,		2·600	,,
7	,,	436·8	,,		3·033	,,
8	,,	499·2	,,		3·466	,,
9	,,	561·6	,,		3·900	,,
10	,,	624·0	,,		4·333	,,
20	,,	1248·0	,,		8·666	,,
40	,,	2496·0	,,		17·333	,,
60	,,	3744·0	,,		26·000	,,
80	,,	4972·0	,,		34·666	,,
100	,,	6240·0	,,		43·333	,,

In comparing quantities of water, certain units of volume are used. These are the cubic foot and gallon.

1 cubic foot $= 6{\cdot}235$ gallons $= 62{\cdot}4$ lbs., or practically, cubic feet x $6\frac{1}{4} =$ gallons, and gallons $\div 6\frac{1}{4} =$ cubic feet.

To the Engineer engaged in Hydraulic Engineering, a knowledge of the principles of Hydraulics is essential, chiefly for two purposes.

First—To determine the discharge of water from natural and other channels, or orifices, of which the regime is known.

Second—To determine the proper form and dimensions of artificial channels or orifices having a certain regime, and capable of conveying or discharging given quantities of water. There are some matters not included in this division of the subject, but they will be touched on further on.

Velocity.

The discharge of water is usually stated as units of volume in units of time. As a first step towards the determination of the discharge through any orifice or channel the velocity must be ascertained.

This is given by the Equation—

$$v = c \sqrt{2gh} \qquad (1)$$

In this Equation, $v =$ velocity in feet per second, $c =$ a constant determined by experiment, and expresses the proportion borne by the actual velocity to what is usually termed the theoretical velocity, the difference being due to friction or contraction, and sometimes to both; $g =$ the velocity acquired at the end of one second by a body falling freely from a state of rest—its value is $32{\cdot}2$ feet per second; $h =$ the distance fallen through by the body, as in the case of a particle of water falling from a higher to a lower level on the surface of a stream, or in the case of a particle passing from a situation of greater pressure to one of a less pressure. Sometimes both these changes are combined. The result is usually stated as "loss of head."

Equation (1) is generally considered the fundamental Equation in Hydraulics.

Velocity is defined in Hydraulic treatises as Mean, Minimum, and Maximum. This may be observed in the running water of a stream where the particles in contact

with the banks will be seen to move with less velocity than those in the centre. It can also be ascertained that the particles in contact with the bed of the stream move less swiftly than the surface particles. It would be impossible from observation to fix the exact portion of the stream whose velocity is a mean of the whole. The mode by which this is determined will be explained further on. In the case of rivers with slow velocities, the minimum, mean, and maximum velocities are as the numbers 2, 3, and 4. In general they are as 3, 4, and 5. If $V =$ greatest velocity, and $v =$ mean velocity, then their relation is given approximately by the Equation

$$v = \cdot 75 \text{ V} \qquad (2)$$

In open channels the loss of head between two points = the fall in the surface of the water. In close pipes it may consist, in part or in whole, of reduction in the head of pressure.

The pressure of water in motion, as thus reduced, is known as Hydraulic Pressure, to distinguish it from Hydrostatic or still-water pressure.

Discharge of Water, &c.

The discharge of water from any orifice or channel is represented by the Equation—

$$Q = V \times A \qquad (3)$$

in which $Q =$ the cubic feet discharged per second; $V =$ the mean velocity in feet per second of the issuing stream; and $A =$ the area in square feet of the orifice or channel at the point of discharge.

The area of the orifice may be found by actual measurement, but the velocity cannot be determined so easily, as will be seen.

Discharge of Rivers.

Where the discharge of a large river has to be measured, the usual method is as follows:—At the point where the discharge is to be ascertained, an accurate cross section of the river bed is made, and the whole width of the surface divided into a number of parallel bands in the direction of the current. The central surface velocity of the water in each of these bands is then found by experiment. A

mean velocity is computed for each, and these multiplied by the respective sectional areas of the bands, will give the discharge of each. The sum of these discharges will be the quantity required.

Let v_1, v_2, v_3—v_n, be the several observed velocities; and a_1, a_2, a_3—a_n, the several areas of the bands. Then the total discharge Q will be—

$$Q = \cdot 75\,(v_1,\, a_1,\, + v_2,\, a_2,\, + v_3,\, a_3,\, + —v_n,\, a_n,)$$

There are several methods for measuring the velocity in the bands. The simplest is by using a float, and noting its rate when passing the line where the measurement is being made. This is but a rough approximation. Another method is by the use of a current meter which consists of a screw fan driven by the water, the revolutions being conveyed through a train of wheelwork to an index dial. The meter is used from a boat, and the central surface velocity determined for each band. Another method is by the use of tubes having their lower ends dipped in the water. The latter will rise to a certain height in the tube, and the amount of this rise is a measure of the velocity of the water. There are several descriptions of these tubes in use, and of late great improvements in their design have been effected, so that results of considerable accuracy are now attainable.

Where the cross section of the river varies much at different points, the foregoing operations should be gone through at several places, and the mean result taken.

Where the river of which the discharge is required is small, it is usual to take the central surface velocity of the water without the sub-division into bands, and the cross section of the stream at the point of measurement. From these the discharge is computed as before.

Discharge from Notches.

In the case of small streams, the usual method of determining the discharge is by passing the water through a notch or check. The practical mode of doing this has been described in a previous chapter. These notches are usually rectangular, but latterly those of a triangular or V form have been used. The velocity of the water passing through the notch will be affected by several circumstances. Thus, where

the notch is the full width of the stream, the effect of friction in retarding the velocity will be different than in the case where the notch is of a less width. It is generally laid down as a rule that the notch should not be less than one-fourth the width of the stream. As will be understood, the effect of putting a notch-board across a stream will be to dam up the water behind it, or, as it is technically expressed, to form a "still pond." In nearly all the calculations relating to the discharge of notches, it is assumed that such a still pond exists, though in point of fact in most cases it is impossible to attain this in practice, as there will be velocity of approach to some extent.

The principles upon which the flow of water through a notch is determined are derived from those of the submerged orifice, which is usually taken in first order. When the water is passed through an orifice whose height does not exceed one half the depth of its centre below the surface, the discharge is represented by

$$Q = 8{\cdot}025 \; c \; A \; \sqrt{h} \qquad (4)$$

where h is measured from the surface of still water to the centre of the orifice. This is accurate so long as the height of the orifice does not exceed one-half the depth of its centre below the surface; but where the orifice is near the surface, the usual method of computation is to divide the orifice into a number of horizontal bands, and the area of each band multiplied by the depth of its centre below the surface. The sum of these products will give the total discharge. The foregoing is usually stated thus :—

$$Q = 8{\cdot}025 \; c \int_{h_0}^{h_1} b \sqrt{h} \; . \; dh$$

In which b = breadth of orifice as before; dh = height of one of the bands; bdh = its area; h = depth of its centre below the surface; h_0 the depth of the upper edge of the orifice; and h_1 the depth of the lower edge below the same level.

The foregoing being simplified in the case of rectangular orifices,

$$Q = 8{\cdot}025\ c\ .\ \tfrac{2}{3}\ b\ (h_1^{\frac{3}{2}} - h_0^{\frac{3}{2}}) \qquad (5)$$

In the case of the surface notch, $h_0 = 0$, and $h_1 =$ depth of water measured from the lower edge of notch to level of surface of still water. Then

$$Q = 8{\cdot}025\ c\ .\ \tfrac{2}{3}\ b\ h_1^{\frac{3}{2}}$$
$$= 5{\cdot}35\ cb\ h_1^{\frac{3}{2}} \qquad (6)$$

This last expression may be used for computation as soon as the proper values of c are known.

Rankine gives the following values for c where the width of the notch bears different ratios to the width of the stream.

Let B = width of stream, and b = width of notch.

$$\frac{b}{B} = 1 \ — \ \tfrac{3}{4} \ — \ \tfrac{1}{2} \ — \ \tfrac{1}{4}$$
$$c = {\cdot}67 — {\cdot}645 — {\cdot}62 — {\cdot}595$$

It will be seen that the values of c vary when the values of $\frac{b}{B}$ undergo a change, but they do not vary with the values of h. In other words, when the ratio of the width of the notch has been fixed, the co-efficient for contraction remains the same for all heads. Now, it has been found by careful experiment that c is not constant for different depths of water flowing through the same notch; consequently, when very accurate results are required, the values of c must be selected suitable for different heads. For full information as to values of c, see "Neville's Hydraulics."

Velocity of Approach.

As already mentioned, it is frequently impossible to obtain a still pond behind the notch, so that the water has what is termed a velocity of approach. This velocity represents a certain fall in the surface of the water when approaching the notch, and if the depth be measured from the edge of the latter, the computed discharge will fall

short of the true one. An approximate method of correcting the result is by observing the velocity of approach, and from this computing the head corresponding to it. Thus if v = velocity of approach, and the head producing it = h_2,

$$\text{Then } h_2 = \frac{V}{8 \cdot 025}$$

And the true discharge will be—

$$Q = 5 \cdot 35cb\ \left((h_1 + h_2)^{\frac{3}{2}} - h_2{}^{\frac{3}{2}} \right)$$

Another method is to measure the depth of water to the level of the edge of the notch at a point some distance up stream. This is done by putting a peg or stump into the bed of the stream, its head being cut to the level of the edge of the notch.

Remarks on Rectangular Notches.

A great many of the gaugings required by engineers are made by means of the Rectangular Notch. The edges of the notch, where in contact with the water, should be chamfered, the edge being to the up stream side. Sometimes the edge is formed with a slip of hoop-iron nailed round. Notches are usually made with their clear opening some even number of feet, for convenience in calculation. Very frequently the depth of water is measured in inches, and the formula used must be arranged for this, or else the inches altered into decimals of a foot. The following are convenient for general use. When the notch is one half the width of the stream and one foot in length, Rankine's formula becomes—

$$Q = 3 \cdot 32\ h^{\frac{3}{2}} = \text{cubic feet per second.}$$
$$= 199 \cdot 2 h^{\frac{3}{2}} = \text{cubic feet per minute.}$$

When the depth of water has been measured in inches, this expression becomes—

$$Q = 4 \cdot 79\ h^{\frac{3}{2}} = \text{cubic feet per minute.}$$

The general formula given by Beardmore is—

$$Q = 5 \cdot 14\ h^{\frac{3}{2}} = \text{cubic feet per minute.}$$

The objections to the use of rectangular gauges are thus stated by Dr. Thompson, of Glasgow :—

"The ordinary rectangular notches, accurately experimented on as they have been at great cost, and with high scientific skill, in various countries, with the view of determining the necessary formulas and co-efficients, for their application in practice, are for many purposes suitable and convenient. They are, however, but ill adapted for the measurement of very variable quantities of water, such as commonly occur to the engineer to be gauged in rivers and streams. If the rectangular notch is to be made wide enough to allow the water to pass in flood times, it must be so wide that for long periods in moderately dry weather the water flows so shallow on its crest that its indications cannot be relied on.

Triangular Notches.

"To remove in some degree this objection, gauges for rivers and streams are sometimes formed, in the best engineering practice, with a small rectangular notch cut down below the general level of a large rectangular notch. If now, instead of one depression being made for dry weather, we use a crest wide enough for use in floods, we conceive of a large number of depressions, extending so as to give the crest the appearance of a set of steps of stairs; and if we conceive the number of such steps to become infinitely great, we are led at once to the conception of the triangular instead of the rectangular notch. The principle of the triangular notch being thus arrived at, it becomes evident there is no necessity for having one side of the notch vertical and the other slanting, but that, as may in many cases prove more convenient, both sides may be made slanting, and their slopes may be alike. It is then to be observed that by the use of the triangular notch, with proper formulas and coefficients, derivable by due union of theory and experiments, quantities of running water from the smallest to the largest may be accurately gauged by their flow through the same notch. The reason of this is obvious, from considering that in the triangular notch, when the quantity flowing is very small, the flow is confined to a small space, admitting of accurate measurement, and that the space for the flow of

water increases, as the quantity to be measured increases, but still continues such as to admit of accurate measurement.

"Another advantage gained by the use of the triangular notch is the fact that the quantity of water flowing through the notch is a function of only one variable, viz., the measured head of water. In the rectangular notch it is a fnnction of at least two variables, viz., the head of water and the width of the notch, and sometimes of a third, which it is difficult to take into account, viz., the depth from the crest of the notch to the bottom of the channel of approach."

Dr. Thompson's expression for the triangular notch described above is—

$$Q = 0{\cdot}317\ h^{\frac{5}{2}} \qquad (7)$$

Q = cubic feet per minute; h = head in inches, measured vertically from still water level of the pool to the vertex of the notch. The sides of the notch to have a slope of 45° with the horizon.

When a = ratio of half breadth of notch at surface water level to h, then $2ah$ = breadth of notch at this level.

$$\text{If } a = 1, \text{ then } Q = 2{\cdot}54\ h^{\frac{5}{2}} = \text{cube feet per second.}$$
$$= 152{\cdot}4 h^{\frac{5}{2}} = \text{,, per minute.} \qquad (8)$$
$$\text{If } a = 2, \text{ then } Q = 5{\cdot}3\ h^{\frac{5}{2}} = \text{cube feet per second.}$$
$$= 318\ h^{\frac{5}{2}} = \text{,, per minute.} \qquad (9)$$

h being taken in feet.

Discharge over Weirs.

It is often convenient to gauge the flow of a stream by passing it over a weir. Such a gauge is formed by throwing an ordinary plank over the stream at such a level as to form a still pond on the upper side. In gauging for preliminary purposes of water supply, weirs of a rough description are sometimes found in rivers, having been put in for mill use. It is often necessary to use these for gauging, to save the time and expense entailed in erecting others.

The usual expression for the flow over such weirs is the same as for rectangular notches; but c, the co-efficient of contraction, has a value of about ·5. The value of c will

vary under different circumstances, as for instance when the crest has a thin edge or a broad one. For values of c reference should be made to "Neville's Hydraulics."

Discharge from Sluices.

Sluices usually come under the class of submerged orifices; where their opening extends to the surface, they are treated as notches already referred to. Where the sluice is submerged, the head is the difference between the level of water on the upper and lower side of the sluice.

The flow in cubic feet per minute is given by the expression—

$$Q = 321\ cb\ \frac{(h_1+h_2)}{2} \sqrt{(h_1-h_2)} \qquad (10)$$

h_1 and h_2 are the heights of the still water above the lower edge of the sluice, opening on the up and down stream side. The value of c may be taken at ·7 when sluice is vertical, and ·8 when it is inclined backwards at an angle of 45° to the horizon.

Rough Gaugings.

In preliminary investigations the engineer is compelled to use such means of gauging streams as come ready to his hand. It frequently happens that streams under examination may be gauged when passing through culverts or square pipes. Where these are very short the flow of water through them may be computed as for rectangular notches, but the value of c must be taken much lower than in the case of a perfect notch. In a similar way a small stream may be sometimes traced to a point where it passes over a ledge of rock or a few large stones in such a way that it may be gauged as for a round-topped weir, giving a suitable value to c. When the streams to be gauged are small it will be found very useful by the engineer to carry with him a small notch of rectangular or V form, cut out of a thin board or tin plate. This can be easily sunk into the stream bed, and the water passed over it. The up stream face should be graduated in inches and quarters from the edge of the notch, and the depth of the water flowing over can be seen at a glance.

Circular Orifices.

Orifices of circular form have been greatly used in experimenting upon the discharge of water. They are also used in districts where water is sold by measure for irriga-

tion. In most cases they are situated below the surface. The head is then measured to the centre of the orifice and the discharge may be calculated by the general expression for submerged orifices. In experimenting with circular orifices in thin plates, high values for c have been obtained.

Uniform Channels.

Most of the artificial channels constructed for the conveyance of water are of uniform section. This is also frequently aimed at in designs for the improvement of streams and rivers. It will thus be seen that an accurate knowledge of the laws of flow in such channels is of primary importance to the engineer.

In former times the usual cross section for conduits was rectangular. Many other forms have been used, but at the present time that most frequently met with is the circular for close conduits, and for open water courses a section having a flat bottom and sloping sides, the angle of the slopes being fixed by the stability of the material passed through.

It has been found that the head due to friction of water in a uniform channel increases directly as the length of the channel, directly as the border or wetted perimeter, and nearly inversely as the sectional area.

The co-efficient of friction varies with the velocity. In most cases it increases as the velocity decreases. The loss of head is also greater for small than for large channels.

If A = the sectional area of a channel, p = the wetted perimeter, or portion of the channel in contact with the water. Then $A \div p = r$ = the hydraulic mean depth or radius, as it is sometimes termed. If l = length of the channel, then the total surface of the channel acted on by the water $= lp$ = frictional surface.

The expression for the friction between the channel and the water is

$$F = \frac{f \cdot l}{r} \qquad (11)$$

For open conduits, $f = \frac{1}{V}\left(\frac{\cdot 0074\ V + \cdot 00023}{}\right)$ (12)

For circular, semi-circular, and square conduits running full, the quantity $r = \frac{d}{4}$. Many open conduits are made with the

sides tangents to a semicircle whose diameter = twice the greatest depth of conduit. In this case r has the above value.

The data required to compute the discharge of a given channel are, the inclination = i; the area of the cross section = A; and the hydraulic mean depth = r. With these, and the value of f already given, the velocity can be determined.

Rankine gives the following general expression—

$$i = \frac{h}{l} = \frac{f}{r} \cdot \frac{V^2}{64 \cdot 4} = \frac{1}{V}(\cdot 0074\,V + 00023) \cdot \frac{V^2}{64 \cdot 4r}$$

The velocity may be obtained from this equation, but it is more convenient to do so by approximation. Assume f = ·007565. Then the resulting value for the velocity will be

$$V = 8 \cdot 025 \sqrt{\frac{ir}{\cdot 007565}} \qquad (13)$$

= a mean proportional between r and the fall in 8,512 feet.

For many purposes this approximation will be sufficiently correct, but where greater accuracy is required a corrected value must be computed for f in the equation already given for that quantity.

Having determined the velocity, the discharge in feet per second will be Q = V A.

The inclination i is frequently stated in feet per mile = h. Equation (13) then becomes, by conversion—

$$V = \cdot 898 \sqrt{2rh} = \text{feet per second.}$$
$$= 53 \cdot 88 \sqrt{2rh} = \text{feet per minute.} \qquad (14)$$

Beardmore's general Equation for the velocity in feet per minute, is—

$$V = 55 \sqrt{2rh} \qquad (15)$$

which is somewhat in excess of the foregoing

Certain forms of Channels have been found to possess greater efficiency than others, though the sectional area may **Cross Sections for Channels.**

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be the same. In other words, the discharging velocity will assume, with certain cross sections of the channel, a maximum value. It is a matter, then, of consequence to the engineer to keep this fact in view, and when designing a channel, to give it, if possible, the most efficient cross section, consistent with the character of the materials passed through.

Mr. Neville states that, other things being the same, that form of channel is the best of which the hydraulic mean depth is a maximum. This qualification includes the semicircle, having the diameter for the surface line; also, half the regular figures as the octagon, hexagon, and square. The half square is the best cross section, and next to it the half hexagon for trapezoidal forms. When the channel is lined with masonry, these forms may be used, but, as a rule, the expense would put them out of the question. Channels are usually cut through clay or other soft material, the side slopes being formed to a safe angle, and the exposed faces protected against the wash of the water. In such cases, the bottom of the channel is usually formed flat, and the sides cut to a slope of $1\frac{1}{2}$ or 2 to 1.

When a channel, with a given area and side slopes, has a discharge of a maximum value, it may be shown that the hydraulic mean depth is one half of the greatest depth. The following mode of construction for the best form of channel is derived from the foregoing by Mr. Neville.

Describe a circle and produce the diameter beyond the circumference at both sides. Draw a tangent to the lower circumference parallel to the diameter. Then draw the side slopes tangent to the circle with the given inclinations, and terminating them at the produced diameter and the bottom tangent. The trapezoid thus formed will be the best form of channel, and the width at the surface will be equal to the sum of the two side slopes.

In some kinds of materials, the foregoing form of channel requires alteration. The usual section, through soft ground, has a flat bottom and side slopes, and the depth small compared with the width.

Circular Conduits. As stated already, when a conduit is covered the circular section is generally used, more especially in the

smaller sizes. The expression for the velocity will be the same as given on page 97.

Taking Beardmore's Equation for the velocity,

$$V = 55 \sqrt{2rh} = \text{feet per minute.}$$

Then the discharge in cubic feet per minute will be—

$$Q = V \times A = 55 \sqrt{2rh} \times d^2 \times {\cdot}7854. \qquad (16)$$

It has been already shown that $r = \frac{d}{4}$; and, substituting this value in the equation, there results—

$$Q = 55 \sqrt{\frac{dh}{2}} \times d^2 \times {\cdot}7854$$

$$= 55 \sqrt{\frac{d^5h}{2}} \times {\cdot}7854$$

$$= 30{\cdot}545 \sqrt{d^5h} \qquad (17)$$

Mr. Hughes gives a convenient form of expression for the approximate velocity in feet per second. It is—

$$V = \sqrt{\frac{dh}{2{\cdot}3}} \text{ and } Q = 31{\cdot}07 \sqrt{d^5h} = \text{cubic feet per min.}$$

The discharge found from these expressions is for the conduit running full. This is, however, unusual in practice. The general rule is to run circular conduits about two-thirds to three-quarters full.

In dealing with conduits of considerable length, the loss of head due to the orifice of entry may be neglected. When, however, the length is small, this must be taken into account.

Discharge of Pipes.

The discharge of any pipe can be determined when the following quantities are known :—h = head in feet, l = length in feet, d = diameter in feet, and f = co-efficient of friction.

$$h = \frac{4fl}{d} \times \frac{v^2}{64{\cdot}4}$$

$4f$ may be assumed as approximately $= \cdot 0258$. Then

$$V = 8 \cdot 025 \sqrt{\frac{hd}{\cdot 0258 l}}$$

$$= 50 \sqrt{\frac{hd}{l}} = \text{feet per second.}$$

$$= 3000 \sqrt{\frac{hd}{l}} = \text{feet per minute.} \qquad (18)$$

The discharge in cubic feet per minute will be—

$$Q = \cdot 7854\, d^2 \times 3000 \sqrt{\frac{hd}{l}}$$

$$= \cdot 7854 \quad \times 3000 \sqrt{\frac{d^5 h}{l}}$$

$$= 2356 \cdot 2 \sqrt{\frac{d^5 h}{l}} \qquad (19)$$

When greater correctness is wished for, $4f$ must be found from the equation

$$4f = \cdot 02 \left(1 + \frac{1}{12d}\right)$$

and the value substituted in Equation (18).

A case which very frequently occurs in practice is when the Engineer requires to determine the diameter of a pipe capable of conveying a given quantity of water with a given fall. This may be done by converting the foregoing equations, so as to give the value for d; but it will often prove more convenient to assume an approximate value for d, and calculate the discharge accordingly. If this result agrees with the given discharge, the assumed value for d is the right one, and if not, another approximation must be made.

Pipe Lines. The expressions just given are based on the assumption that the line of pipe is free from bends, either in the vertical or horizontal plane—at least such bends as would in any way obstruct the flow of the water. Where bends occur they produce loss of head, and in determining the discharge

of a length of pipe, with a number of bends, the total loss of head due to them must be taken into account.

For bends in circular pipes,

$$F = \frac{A}{n}\left(0{\cdot}131 + 1{\cdot}847\left(\frac{d}{2r}\right)^{\frac{7}{2}}\right) \qquad (20)$$

in which A = angle of bend, n = two right angles, and r = radius of bend on centre line.

When the curves are in the vertical plane, and are due to changes of level, they do not, as a rule, require to be taken into account in the same manner as the ordinary bends. In any pipe line, when the pipe is of uniform bore throughout, the best condition is that the slope or grade should be uniform also. This is frequently impossible, owing to the undulating character of the ground passed through; and, to save the expense of deep sinking, the undulations have to a large extent to be repeated in the pipe section. Suppose now a line of pipe laid between two points. The straight line joining these points is sometimes termed "the hydraulic mean gradient." When the line of pipe falls below this gradient at any point, no bad effects follow; but when it goes above it at any point obstruction will ensue. At such a point air from the water will collect, and prevent the free flow of the latter.

In addition to the allowance for loss of head at bends, the loss due to entry of the water into the pipe must be taken into account.

The diameter of the pipe calculated for a straight line should be increased in the proportion $(1 + F)\ r^2 \div 64{\cdot}4$. F = the proper factor for the friction of the mouthpiece.

Having determined the diameter of a pipe, and made all the foregoing corrections, it is usual in addition to add something to the diameter, as an allowance for corrosion. For this purpose some authorities add one sixth, but the most usual course is to increase the diameter by an inch.

One of the most troublesome matters in connection with a system of town supply is the arrangement of the various lines of main piping, having due regard to efficiency on the one hand and economy on the other. In practice

the questions resolve themselves into the laying down certain lines of main piping of different diameters, capable of conveying given quantities of water to given points on the route. The best way to determine the diameters is to divide the main into sections, and compute the diameter capable of discharging the required quantity of water at the first point. The head for this first length must be first ascertained from the working section of the pipe line. In a similar manner the diameter for the next length of main must be calculated.

The following mode of determining the arrangement of a line of main pipes is given by Mr. Hawksley. Supposing a street of 600 yards in length to be supplied. This should be divided into sections of 200 yards each. The quantity of water to be allowed to each of these sections should be as follows:—

				Gals. per day.
Final 200 yards,		... ...	=	13,000
Middle,	„	11,000 + 13,000	=	24,000
First,	„	8,000 + 24,000	=	32,000

It is assumed that the total consumption will take place in four hours, and that the quantities will be delivered to the end of each length. By Hawksley's Equation already quoted the pipes capable of passing these quantities will be

Final 200 yards,	...	3·6 inches diameter.
Middle „	...	4·5	„
First „	...	5·2	„

Or pipes of say 6, 5, and 4 inches diameter.

Mr. Hawksley's formula for calculating the discharge of water is—

$$G = \sqrt{\frac{(15\,d)^5 h}{l}} \qquad (21)$$

in which G = gallons discharged per hour; d = diameter of pipe in inches; h = head of water in feet; and l = length of pipe in yards.

Another convenient formula, taken from "Molesworth's Pocket Book," is—

$$Q = 4{\cdot}72 \frac{\sqrt{d^5}}{\sqrt{\frac{l}{h}}} \qquad (22)$$

in which Q = cubic feet discharged per minute; d = diameter of pipe in inches; l = length of pipe in feet; and h = head in feet.

Discharge through short Pipes.

The foregoing expressions for the discharge of pipes are only applicable when the length is considerable. For short pipes a separate value for friction must be used for each case. For purposes of calculation the length of the pipe is expressed in terms of the diameter.

The following Table, abridged from one by Mr. Neville, will be found of service in computing the discharge from short pipes:—

Table of Co-efficients for Short Pipes.

F = ·00699. Velocities about 1·5 feet per second. Mouthpieces, round-edged, common square-edged, and projecting into Reservoir.

Co-efficients of Discharge = c.

Length of Pipe in diameters.	Round-edged Mouthpiece.	Square-edged Mouthpiece.	Mouthpiece projecting into Reservoir.
2	·986	·814	·715
5	·936	·779	·690
10	·884	·747	·668
15	·840	·720	·649
20	·801	·695	·630
25	·767	·673	·615
30	·737	·653	·598
35	·711	·634	·584
40	·693	·617	·570
45	·665	·601	·558
50	·646	·586	·546
100	·513	·480	·458

Length of Pipe in diameters.	Round-edged Mouthpiece.	Square-edged Mouthpiece.	Mouthpiece projecting into Reservoir.
150	·439	·418	·403
200	·389	·373	·364
250	·354	·345	·334
300	·327	·318	·311
350	·304	·297	·292
400	·287	·280	·276
450	.271	·266	·262
500	·258	·254	·250
550	·247	·243	·240
600	·237	·234	·231
650	·228	·225	·223
700	·220	·217	·215
750	·213	·211	·209
800	·206	·205	·203
850	·201	·199	·197
900	·195	·193	·192
950	·190	·189	·187
1000	·186	·184	·183

The most convenient mode of using the Table is to find the velocity from the Equation

$$v = c \times 8{\cdot}025 \sqrt{h} \qquad (23)$$

c will be found in the Table opposite the number corresponding to the number of diameters in the length of pipe. Where the case under discussion gives a different number of diameters to any found in the Table, it will be sufficiently accurate to take the nearest value of c, or else an interpolated value may be taken.

The above Table will be found useful in many special cases.

Co-efficients. From what has been already stated, it will be seen that the various expressions for the discharge of water from orifices, weirs, etc., are accurate only when the co-efficients are reliable. Hence a considerable amount of experience and judgment is necessary to secure correct results from hydraulic calculations. In dealing, therefore, with particular cases, such as frequently occur in gauging, the engineer

must examine into the various matters affecting each individual case, and then select co-efficients which have been derived from experiments made under similar conditions. Without attention to such particulars, calculated discharges cannot be accepted as trustworthy.

It sometimes happens that a long series of gaugings has to be taken, with a given form of orifice or notch. In such a case, co-efficients may frequently be determined from actual experiment. This most generally occurs when the quantities of water are small. The mode of finding the co-efficient of discharge is to turn the water for a given time into a receptacle of known capacity. This will give the actual discharge. The theoretical discharge may be computed from the proper expression. The co-efficient is then ascertained by dividing the actual by the theoretical discharge.

Horse Power of Water.

It frequently happens that the value of water as a motive power has to be determined in connection with schemes of town supply. As soon as a stream is selected for examination by a local authority, the different landholders along its banks become actively alive to its value as a source of power. Every fall on the stream becomes a suitable site for a mill. Existing mill interests are also sometimes affected, and it is, therefore, incumbent on the engineer engaged to form an accurate estimate of all damage likely to result to such interests by the carrying out of works of water supply.

The power of water is reduced to the ordinary standard of horse power. The power of a horse is assumed as that capable of lifting a weight of 33,000 lbs. one foot high in one minute. This is not now considered a correct estimate, but it has prevailed so long that a change to any other standard would be a matter of great inconvenience and confusion.

To determine the value in horse power of a fall of water, the first step necessary is to gauge the stream at the point in question. The gaugings should be reduced to cubic feet per minute. The total fall has then to be determined. Let $Q =$ the cubic foot per minute falling through the height h. A cubic foot of water may be taken $= 62{\cdot}4$ lbs.

The total work of the fall will then be—

$$62{\cdot}4 \times Q \times h$$

and the total power will be—

$$P = \frac{62{\cdot}4 \times Q \times h}{33{\cdot}000} \quad (24)$$

$$P = 0{\cdot}00189\ Q\ h \quad (25)$$

This expression gives the theoretical power of the water. The actual power will, of course, depend on the prime mover employed, and its state of efficiency or otherwise. The prime movers used are the water wheel, turbine, and water pressure engine. Water wheels are divided into classes according to the mode in which the water is applied They are known as overshot, breast, and undershot.

Efficiency of Prime Movers.

The efficiency of these prime movers is as follows :—

Theoretical H.P.	=	1·00
Overshot Wheel	=	·70
Breast Wheel	=	·55
Undershot Wheel	=	·35
Outward Flow Turbine	=	·70
Inward Flow Turbine	=	·75
Water Pressure Engine	=	·80

Power of a Fall.

In determining the horse power of a wheel in operation, it will generally be found convenient to gauge the water in the trough or shoot which passes it from the head race to the wheel. This will be done most easily by finding the velocity with a float, and the section of the trough by actual measurement. The fall through which the water operates can be determined by levelling down to the tail race.

When the fall, the power of which has to be determined, is unused, and not supplied with any prime mover, there is no difference in the operations required from those first mentioned.

Value of Falls Unused.

It is often a matter of importance to determine the commercial value of a fall of water. The method of settling

this value is by calculating the cost of replacing the water power by that of steam. A rough average value is sometimes assumed—viz., £3 per annum per horse power. The annual cost of replacing a horse power of water by one of steam must necessarily vary with the locality, price of coal, and other particulars. To illustrate this by an ordinary case, assume an unused fall of say 60 feet. The minimum run in the river = 30 cubic feet per minute. By the making of a dam this could be increased to 50 cubic feet per minute. The power of the fall will then be—

$$\begin{aligned} P &= 0 \cdot 00189 \times 50 \times 60 \\ &= 5 \cdot 67 \\ &= \text{say } 5\tfrac{2}{3} \end{aligned}$$

Assume now that the cost of rendering the fall available by putting up a prime mover and erecting necessary works, including the dam above-mentioned, would amount to £500.

Interest on this outlay at 5 per cent. = ...	£25	0	0
Depreciation fund for renewals at 10 per cent. =	50	0	0
Workmen's wages—One man at	40	0	0
Oils, etc., say	15	0	0
Total annual cost of making fall available ...	£130	0	0
or, per horse power, say = ...	23	0	0

Supposing now that the fall is to be rendered valueless by the abstraction of the water, and steam to be substituted, the estimation of the cost of so doing is as follows :—

Cost of 5⅔ H.P. nominal, engine and boiler, say = ...	£120	0	0			
Buildings, etc., say	100	0	0			
Interest on £220 at 5 per cent. = ...				£11	0	0
Depreciation fund for renewals, 10 per cent. =				22	0	0
Engine-driver's wages, say				47	0	0
Coal taken at 4 lbs. per indicated H.P. per hour, and engine working at twice the nominal power, 64 tons at say 15s.				48	0	0
Oils, etc., ...				15	0	0
Total annual cost of steam power ..				£143	0	0
or, per horse power, say = ...				25	4	6

The steam power would thus cost the owner of the fall at the rate of £2 4s. 6d. per horse power per annum above the water if made available. This amount will represent the prime value of the water power per annum per horse power. The total value is usually found by capitalizing the annual value at fourteen or fifteen years' purchase. The number of years' purchase has been fixed by usage, and the reason for this usage is that the annual value is contingent on so many circumstances that it could not be estimated in the same way as a well-secured annual charge.

Taking the years' purchase as fourteen there results :—

$$5\tfrac{2}{3} \times £2\ 4s.\ 6d. \times 14 = £182\ \ 0\ \ 0$$
$$= \text{prime value of fall.}$$

In many cases a fall of water is of little or no value, because the cost of making it available would exceed the cost of erecting a steam engine. Hence it is essentially necessary that engineers should be able to determine with accuracy the condition of the falls proposed to be interfered with, and avoid, if possible, the necessity for compensation.

Value of Falls in use.

It sometimes becomes necessary to abstract water from a fall which is in actual use. Where this cannot be met by storage, compensation must be made in money. To arrive at the amount of the damage done will entail a little more difficulty than the first case, which has been gone into. In this case new machinery may have to be erected to make up for the lost water power, and allowance must be made for interruption to business.

Pumping.

As mentioned in a former part of this work, artificial power has to be resorted to in some cases to raise the water. This is done in two ways—firstly, by pumping the water up to a high service reservoir of sufficient altitude to command the district of supply ; secondly, by pumping directly into the pipes.

Pumping by steam power is generally out of the reach of local authorities in small towns on the ground of expense, and when the water which has to be raised to a higher level is small in quantity it will often be possible to effect the

object by water power. Thus, when the supply is to be drawn from a river with a fair fall and considerable volume, a good plan will be to put down a low pressure turbine working a ram pump. An arrangement of this kind can be made almost self-acting, and the annual cost of working will be very small.

In designing such an arrangement, the first step will be to fix the work of the pump—that is, the quantity of water to be raised and the height of the lift. This will be expressed by

$$W = Q \times 62{\cdot}4 \times h$$

When W = work to be done in foot lbs. Q = cubic feet per minute to be raised, and h = the lift in feet. This expression, if divided by 33·000, gives the H.P. of the prime mover which is to work the pump. Thus :—

$$P = \frac{Q \times 62{\cdot}4 \times h}{33{\cdot}000}$$

$$P = \frac{Q \times h}{528{\cdot}8} \qquad (26)$$

It is usual to add from 30 to 80 per cent. to the value of P for friction and contingencies.

For convenience of reference, a Summary of the foregoing *formulæ* is given at the end of this chapter. It will be found of service when time is too limited to permit the determination of expressions in a scientific manner.

SUMMARY.

THEORETICAL VELOCITY.

$$v = 8{\cdot}025 \sqrt{h} = \text{feet per second.}$$

MEAN VELOCITY OF STREAMS.

$$v = {\cdot}75\,V$$

DISCHARGE FROM ORIFICES.

When the height does not exceed one-half the depth of its centre below the surface—

$$Q = 8{\cdot}025\ c\ A\ \sqrt{h} = \text{cubic feet per second.}$$
$$= 481{\cdot}5\ c\ A\ \sqrt{h} = \text{cubic feet per minute.}$$

DISCHARGE FROM RECTANGULAR NOTCHES

$$Q = 5{\cdot}35\ cb\ h^{\frac{3}{2}} = \text{cubic feet per second.}$$
$$= {\cdot}321\ cb\ h^{\frac{3}{2}} = \text{cubic feet per minute.}$$

When $\frac{b}{B} = 1 — \frac{3}{4} — \frac{1}{2} — \frac{1}{4}$

then $c = {\cdot}67 — {\cdot}645 — {\cdot}62 — 595$

and $Q = 215\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = 1$

or $Q = 5{\cdot}17\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = 1$

When h is measured in inches—

$Q = 207\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{3}{4}$

or $Q = 4{\cdot}98\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{3}{4}$

When h is measured in inches—

$Q = 199\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{1}{2}$

or $Q = 4{\cdot}79\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{1}{2}$

When h is measured in inches—

$Q = 191\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{1}{4}$

or $Q = 4{\cdot}59\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = \frac{1}{4}$

When h is measured in inches (Beardmore's formula)—

$Q = 5{\cdot}14\ b\ h^{\frac{3}{2}}$ cubic feet per minute when $\frac{b}{B} = 1$

DISCHARGE FROM TRIANGULAR NOTCHES.

Thompson's Formula.

$Q = 0{\cdot}317\ h^{\frac{5}{2}}$ = cubic feet per minute, h being measured in inches, and sides having a slope of 45° with the horizon.

Rankine's Formula, when $a = 1$.

$$Q = 152{\cdot}4\ h^{\frac{5}{2}} = \text{cubic feet per minute.}$$

$$\text{or } Q = 0{\cdot}306\ h^{\frac{5}{2}} = \text{cubic feet per minute.}$$

when h is measured in inches.

When $a = 2$—

$$Q = \quad 318\ h^{\frac{5}{2}} = \text{cubic feet per minute.}$$

$$\text{or } Q = 0{\cdot}637\ h^{\frac{5}{2}} = \text{cubic feet per minute.}$$

When h is measured in inches—

a = ratio of half breadth of notch at water level to h.

DISCHARGE FROM SLUICES.

$$Q = 321\ c\ b\left(h_1 + \frac{h_2}{2}\right)\sqrt{\left(h_1 - h_2\right)}$$

h_1 and h_2 are the heights of the still water above the lower edge of sluice.

$c = {\cdot}7$ when sluice is vertical.

$c = {\cdot}8$ when it is inclined backward at an angle of 45° to the horizon.

When the sluice is submerged, as already defined,

$Q = 481{\cdot}5\ c\ .\ A\sqrt{h}.$ = cubic feet per minute, taking $c = {\cdot}7.$

$$Q = 337\ .\ A\sqrt{h.}$$

h = difference of level of water above and below the sluice.

DISCHARGE FROM UNIFORM CHANNELS.

$$v = 53{\cdot}88\ \sqrt{2\ rh} = \text{feet per minute.}$$

BEARDMORE'S EXPRESSION.

$$v = 55 \sqrt{2\,rh} = \text{feet per minute.}$$

$$r = \text{hydraulic mean depth} = \frac{\text{sectional area.}}{\text{wetted perimeter.}}$$

DISCHARGE FROM CIRCULAR CONDUITS.

Running Full.

$$Q = 30{\cdot}545 \sqrt{d^5\,h} = \text{cubic feet per minute.}$$

HUGHES' EXPRESSION.

$$Q = 31{\cdot}07 \sqrt{d^5\,h} = \text{cubic feet per minute.}$$

DISCHARGE FROM PIPES.

$$v = 50 \sqrt{\frac{hd}{l}} = \text{feet per second.}$$

$$v = 3000 \sqrt{\frac{hd}{l}} = \text{feet per minute.}$$

$$Q = 2356{\cdot}2 \sqrt{\frac{d^5 h}{l}} = \text{cubic feet per minute.}$$

This becomes—

$$Q = 4{\cdot}72 \frac{\sqrt{d^5}}{\sqrt{\frac{l}{h}}} = \text{cubic feet per minute,}$$

in which d is measured in inches.

DISCHARGE FROM SHORT PIPES.

$$v = 481{\cdot}5\ c \sqrt{h} = \text{feet per minute.}$$

c to be found from table on page 103.

$$\therefore Q = A\,.\,v = \text{cubic feet per minute.}$$

HORSE POWER OF WATER.

$$P = 0{\cdot}00189\ Q\,.\,h.$$